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Human Infrastructure System Assessment for Military Operations

Infrastructure and the Operational Art

A Handbook for Understanding, Visualizing, and Describing Infrastructure Systems

Steven D. Hart, J. Ledlie Klosky, Scott Katalenich, Berndt Spittka, and Erik Wright

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A Handbook for Understanding, Visualizing, and Describing Infrastructure Systems

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Final report

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Abstract

The Army's understanding of infrastructure as an operational variable has been evolving over the past 30 years in response to significant events ranging from international conflicts to domestic weather-related disasters. These experiences have combined to drive a significant shift in infrastructure doctrine, which now demands that commanders and staffs understand, visualize, and describe the infrastructure variable to accomplish the Army's assigned infrastructure missions of protecting, restoring, and developing infrastructure—all missions essential to restoring stability after conflict or disaster. Current Army doctrine, however, does not say how commanders and staffs are to approach these challenging tasks. This report presents a cognitive framework for understanding, visualizing, and describing infrastructure by using five conceptual models created to allow commanders and staffs to think critically, creatively, and completely about infrastructure problems. The report also includes the scholarship behind the models including verification, validation, and certification as well as example applications of the models to actual situations. Infrastructure is a concern for both civil society and the military, and the models work equally well in both. The authors actively solicit feedback from any reader on the use, application, and improvement of these models.

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Preface

This study was conducted for the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA(ALT)) under Project #405479, "Human Infrastructure System Assessment for Military Operations." The technical monitor was Mr. Hany Zaghloul, program manager, U.S. Army Engineer Research and Development Center-Construction Engineering Research Laboratory (ERDC-CERL).

The work was performed by the Ecological Processes Branch (CN-N) of the Installation Division (CN) of ERDC-CERL. At the time of publication, Mr. William D. Meyers was Chief, CEERD-CN-N; Ms. Michelle Hanson was Chief, CEERD-CN; and Mr. Ritchie L. Rodebaugh, CEERD-TZ-T, was the Acting Technical Director for Geospatial Research and Engineering. The Deputy Director of ERDC-CERL was Dr. Kirankumar Topudurti, and the Director was Dr. Ilker Adiguzel.

The authors acknowledge that important contributions to this work were made by Mr. Christopher Conley, Ph.D.; COL Joseph P. Hanus, Ph.D., P.E.; COL K. Fred Meyer, Ph.D., P.E.; MAJ Morgan Reese, P.E.; and MAJ Jason Toth, P.E.—all of the Department of Civil and Mechanical Engineering at West Point Military Academy.

COL Jeffrey R. Eckstein was the Commander of ERDC, and Dr. Jeffery P. Holland was the Director.

Abbreviations

Term	Meaning
AAR	After Action Review
ADP	Army Doctrinal Publication
ADRP	Army Doctrinal Reference Publication
AIF	Afghan Investment Fund
AOKOC	avenues of approach, observation and fields of fire, key terrain, obstacles, cover and concealment (military aspects of terrain)
ASCE	American Society of Civil Engineers
ASCOPE	areas, structures, capabilities, organizations, people, and events (civilian considerations
BOK2	short title applied to *ASCE Body of Knowledge*, 2nd edition
BSTB	Brigade Special Troops Battalion
CERL	Construction Engineering Research Laboratory
CERP	Commander's Emergency Response Program
CCI	Committee on Critical Infrastructure (for ASCE)
CLOIS	complex, large-scale, integrated, open systems
COA	course of action
CPA	Coalition Provisional Authority
DABS	Da Afghanistan Breshna Sherkat
DAC	District Advisory Council
DCO	Defense Connect Online
DoD	Department of Defense
ECCC	Engineer Captains Career Course
ERDC	Engineer Research and Development Center
FM	field manual
GBDUWC	Grizzly Bears Don't Use Water Closets (mnemonic)
ID	Infantry Division
IRRF	Iraq Relief and Reconstruction Fund
ISI	Institute for Sustainable Infrastructure
INVEST	Infrastructure Voluntary Evaluation Sustainability Tool
JEOC	Joint Engineer Operations Course
LED	local economic development
LEED	Leadership in Energy & Environmental Design
LIPA	Long Island Power Authority
MCEER	Multidisciplinary Center for Earthquake Engineering Research
MDMP	military decision-making process

Term	Meaning
METT-TC	mission, equipment, time, terrain, troops, civilians (mission variables)
MOPH	Minister of Public Health
MSIAC	Munitions Safety Information Analysis Center
NAE	National Academy of Engineering
NGO	nongovernment official
NJIT	New Jersey Institute of Technology
NYU	New York University
OIF	Operation Enduring Freedom
PMESII-PT	political, military, economic, social, information, and infrastructure–physical environment and time (operational variables)
RSOI	reception, staging, onward movement, and integration
SAMS	School of Advanced military Studies
SCADA	supervisory control and data acquisition
SIGIR	Special Inspector General for Iraq Reconstruction
SIGAR	Special Inspector General for Afghanistan Reconstruction
SOI	Sons of Iraq
SWEAT-MSO	sewage, water, electricity, academics, trash, medical, safety, other (infrastructure sectors
TF	Task Force
TISP	The Infrastructure Security Partnership
UFC	Unified Facilities Criteria
UN	United Nations
USACE	U.S. Army Corps of Engineers
USAID	U.S. Agency for International Development
USG	U.S. Government
USGBC	U.S. Green Building Council
VTC	video teleconference
WEF	World Economic Forum
WTP	water treatment plant

Foreword

> The real danger as the United States withdraws from Afghanistan and Iraq is that U.S. military commanders and civilian policymakers will purge the whole experience of counterinsurgency from institutional memory, as occurred in the aftermath of Vietnam, resetting the U.S. armed forces to fight large-scale wars against conventional enemies.
>
> Fernando Lujan (2012)

As with much of the evolving post-conflict doctrine, what appears in this report will be very familiar to those of us with experience in Iraq and Afghanistan; it will not be familiar to those that follow us. This report is written for them in the hopes that the lessons of the recent past will be truly learned, codified in doctrine and procedures, and taught to the next generation.

LTC Steven D. Hart – May, 2014
ERDC Engineering Fellow
West Point, NY

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1 Introduction

1.1 Background

By virtue of the way we live modern life, almost everyone in societies with any level of development is familiar with infrastructure and relies on its benefits. We turn on lights. We flush toilets. We eat food that we did not grow. Familiarity with infrastructure, however, is not synonymous with understanding; when infrastructure questions arise that require deeper levels of understanding, transforming familiarity into understanding can be challenging. To compound this challenge, infrastructure issues are often social rather than technical and require systems-level societal solutions supported by in-depth technical understanding. As such, achieving consensus on infrastructure challenges involves many different, often divergent, elements of society, all with different perspectives, knowledge bases, and agendas.

The challenge of understanding infrastructure extends to military operations. Modern warfare is “warfare amongst the people” (Smith 2005), and so modern warfare takes place in and around civilian populations and the infrastructure that supports both civilians and combatants. The need to understand civilian infrastructure is thus as essential for the general as it is for the city manager. For Army engineers, who respond to both generals and city managers and are rightly seen as experts in infrastructure, the need to understand infrastructure is all the greater.

Since shared definitions are essential to the shared understanding necessary to reach consensus, the terms infrastructure, operational art, and operational variable are defined here.

1.1.1 “Infrastructure” defined

The word infrastructure has many definitions, each tailored to the particular perspective of the author. Each is correct for the needs of the author but in a broader, conceptual sense, multiple definitions taken together are necessary for a complete understanding. The U.S. Army states that infrastructure “is composed of the basic facilities, services, and installations needed for the functioning of a community or society” (U.S. Army 2012a). The Department of Homeland Security, in the National Infrastructure Protection Plan, uses a broader definition: “The framework of interdependent networks and systems comprising identifiable industries, institutions (including people and procedures), and distribution capabilities that provide a reliable flow of products and services essential to the defense and economic security of the United States, the smooth functioning of government at all levels, and society as a whole. Consistent with the definition in the Homeland Security Act, infrastructure includes physical, cyber, and/or human elements" (Department of Homeland Security 2009). James Carlini, taking a business-focused approach, defines infrastructure as "a platform for commerce and economic growth" (Carlini 2009).

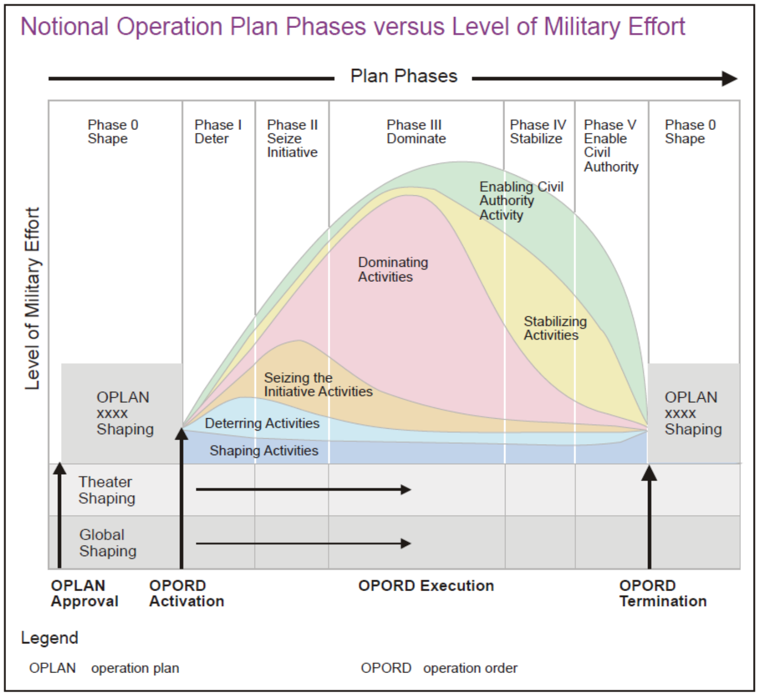
Considering these definitions of infrastructure, the following critical elements of infrastructure emerge.

- Infrastructure is the mechanism that delivers the fundamental needs of society: food, water, energy, shelter, governance. Very simply, without infrastructure, societies disintegrate and people die.
- Infrastructures are, by definition, networks. These infrastructure networks are inter- and intra-connected and dependent systems. Failure of a small number of elements in the infrastructure can cause the entire system to fail. Additionally, failure in elements of one infrastructure can cascade to another dependent infrastructure.
- Infrastructure is the platform on which the economy functions and prosperity depends. Infrastructure supports essential economic functions such as production, transportation, communications, payroll, and employment.

1.1.2 "Operational art" defined

"Operational art" is a term that refers to "the pursuit of strategic objectives, in whole or in part, through the arrangement of tactical actions in time, space, and purpose" (U.S. Army 2011a). While a military term, operational art is also applicable to government, business, and society. Operational art links individual projects into coherent programs to achieve objectives by spanning disciplines and bringing together elements of disparate fields such as finance, design, stakeholder analysis, and strategic communications to build consensus. Operational art can be practiced by anyone at any level when bringing together multiple elements to achieve a greater whole. Figure 1 shows the notional phases of a joint operational plan (DoD 2011). It is the operational art that links a Phase II decision to destroy a bridge so that the enemy *cannot* use it for a counter attack to a Phase IV decision to rebuild the bridge so that commerce *can* use it. When practiced well, operational art never results in someone coming up to a piece of destroyed infrastructure and saying, “Dang, I sure wish we hadn’t done this!” or “Boy, was that an expensive decision for a marginal gain.”

Figure 1. Notional phases of a joint operational plan.



1.1.3 “Operational environment” defined

An operational environment is “a composite of the conditions, circumstances, and influences that affect the employment of capabilities and bear on the decisions of the commander” (U.S. Army 2012a). An operational environment may be described through the use of operational variables, namely “those aspects of an operational environment, both military and nonmilitary, that may differ from one operational area to another and affect operations. Operational variables describe not only the military aspects of an operational environment but also the population’s influence on it.” The Army employs the six joint operational variables: political, military, economic, social, information, and infrastructure, and to these it adds physical environment and time. These variables are often abbreviated as PMESII-PT (U.S. Army 2012a). While conceived for military operations, these variables are also useful in understanding societies outside of conflict zones if the military variable is replaced with public safety, security, or emergency services.

1.2 Objective

This technical report presents a cognitive framework for understanding, visualizing, and describing infrastructure under any condition to any audience. It presents a transilient* cognitive architecture to allow commanders, leaders, planners, managers, and citizens to think critically, creatively, and completely about infrastructure problems; to identify and engage with all stakeholders; and to formulate and implement solutions that are technically, socially, environmentally, economically, and politically viable.

1.3 Approach

> People may not need a well; what they really need is water. We won't get it right all the time, but at least we can get it right more often by asking a lot of people. Ask the sheik, but trust and verify after getting his input....We put out numerous compact water units around the country because we knew fresh water was a problem at lots of places around the country. *People would sit in their houses and have no water because no one thought about connecting them up to houses.* General Chiarelli would constantly tell me to consider the [systems] perspective.
>
> MG Kendall Cox (Cox 2011)
> (*emphasis added*)

The above excerpt represents a *lesson observed* from Operation Iraqi Freedom, as reproduced in a report for the U.S. Army Corps of Engineers from a conversation with that report's author, Dr. Russell W. Glenn (Glenn 2012). This lesson (and all the others contained in that 340-page report) will not become *lessons learned* until commanders, leaders, engineers, and staff officers are taught to think critically, creatively, and completely about infrastructure identification, assessment, development, and resilience and then adjust their actions accordingly. This technical report begins that process by proposing a simple, coherent, and orderly way of thinking about and addressing infrastructure problems that can be taught to anyone.

In 2012, Dr. Glenn published *Core Counterinsurgency Asset: Lessons from Iraq and Afghanistan for United States Army Corps of Engineer*

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* Transilient means "leaping across" or "transitioning from one state to another." It is the quality of transilience that allows models presented to be adapted to fit different circumstances and needs.

Leaders (Glenn 2012) under a research effort sponsored by USACE. His report is based on an extensive literature review and interviews with some 100 individuals with experience in Iraq, Afghanistan, and other locations. Glenn's report includes 107 recommendations, some of which can be implemented at the unit level, and others of which would require U.S. Congressional action. Although Dr. Glenn's report was not used in the development of the concepts presented in this report because its 31 May 2012 publication was after this report's models were developed, it is heavily referenced in this report because our experiences and research revealed the same lessons that Dr. Glenn compiled. The fact that the independent research of this report's authors and Dr. Glenn's work reached similar conclusions serves to validate the work of both. In our literature review, we heavily annotated Dr. Glenn's report; this annotated copy is available from the authors of this report.

During the initial development of an infrastructure survey course at the United States Military Academy, a number of infrastructure areas were selected for inclusion in the syllabus, including topics like water and wastewater, electrical power, and transportation. In attempting to set these topics into an understandable framework (especially for students pursuing nontechnical majors), the team of instructors sought overarching models or frameworks which described the infrastructure and addressed in a coherent way the essential elements of a successful infrastructure system. The need for such a model or framework was seen as an essential task in light of ongoing military operations in Afghanistan and Iraq at the time and the pivotal role of infrastructure in the execution of those missions.

Unfortunately, no infrastructure models existed that met the Academy's instructional needs. Thus the decision was made to work towards developing thought frameworks or models that could be used to guide systems-level thinking about infrastructure for both a student and graduate. Army doctrine related to operations, leader functions, and design were reviewed in detail, as were the experiences of the many recently-operational officers who were then posted to West Point. When combined with the considerable engineering experience of the civilian faculty at West Point and the broader academic network, this threefold approach of consulting doctrine, military experience, and civilian expertise proved a strong underpinning for the development of the models presented in this report.

The resulting models are presented in detail in Chapter 4 of this report, and they broadly cover the infrastructure environment, its components, assessment, development, and resilience. Since these models are meant to provide a broad approach to any of the many infrastructure areas and the areas addressed overlap between fields as diverse as engineering, politics, economics and sociology, there can be no resulting model that can be defined as formally correct or complete. Like many economic or social models, the thought framework presented can and should be constantly improved upon as our understanding of infrastructure improves. That said, the authors undertook a broad program to validate the models through use, scholarly review, and broad discussion with the professional communities of practice in education, the Army, and the civil engineering profession. Throughout the process of publication and presentation (both formal and informal), careful note was made of all feedback and observations, some of which is described in the journal article by Hart, Klosky, and Katalenich (2013).

Important milestones in the development and feedback process include:

- Multiple presentations at the Captains' Career Course, the Command and General Staff College, and the U.S. Army War College, where formal and informal feedback was sought from instructors and the operationally experienced Army officers taking the courses.
- Discussions with and feedback from Mr. Blaine Leonard, who at the time was President of the American Society of Civil Engineers (ASCE), and Dr. Paul Mlakar, a senior scientist with the U.S. Army Engineering Research and Development Center (ERDC).
- Publication of the models and/or course development processes and results in multiple venues including the ASCE journal system, the American Society of Engineering Education, and the Critical Infrastructure Symposium.
- Invited presentation of the models in detail to a large audience of practitioners at the national convention of the ASCE (2013) and presentation via webinar through the ASCE system.
- Use of the models across eight semesters of instruction at West Point, including at least six different instructors, four of whom had seen extensive deployment in Iraq and Afghanistan.

At every step, feedback was sought, especially from subject-matter experts; this feedback was then carefully considered and incorporated into the resulting models. This process yielded a set of models that is robust, clear, and extensively tested through use and publication.

2 Infrastructure in the Early 21st Century

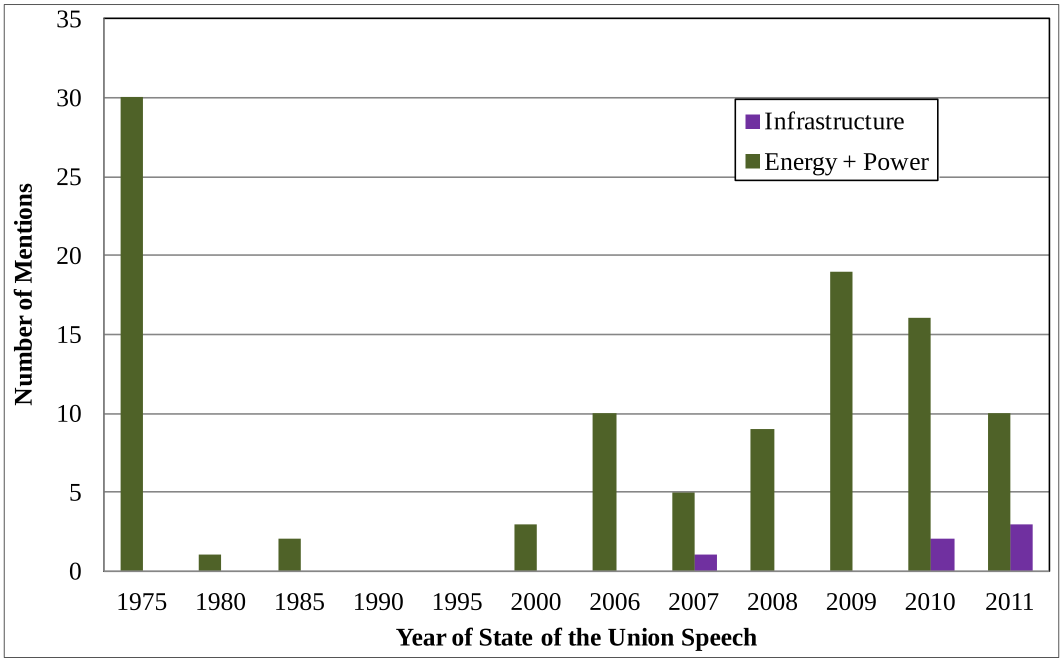
2.1 Infrastructure in society

In the United States, our history is one of federal support for building great infrastructures such as the National Road, Erie Canal, transcontinental railways, inland navigation coupled with flood mitigation and control, the Panama Canal, and the interstate highway system. We have also recognized the importance of restoring ravaged infrastructures following major conflicts and natural disasters as evidenced by the Marshall Plan following World War II and our efforts in improving seismic design and construction over the last century. In spite of these laurels, some of our recent infrastructure endeavors have been less than stellar.

2.2 Recent public discourse

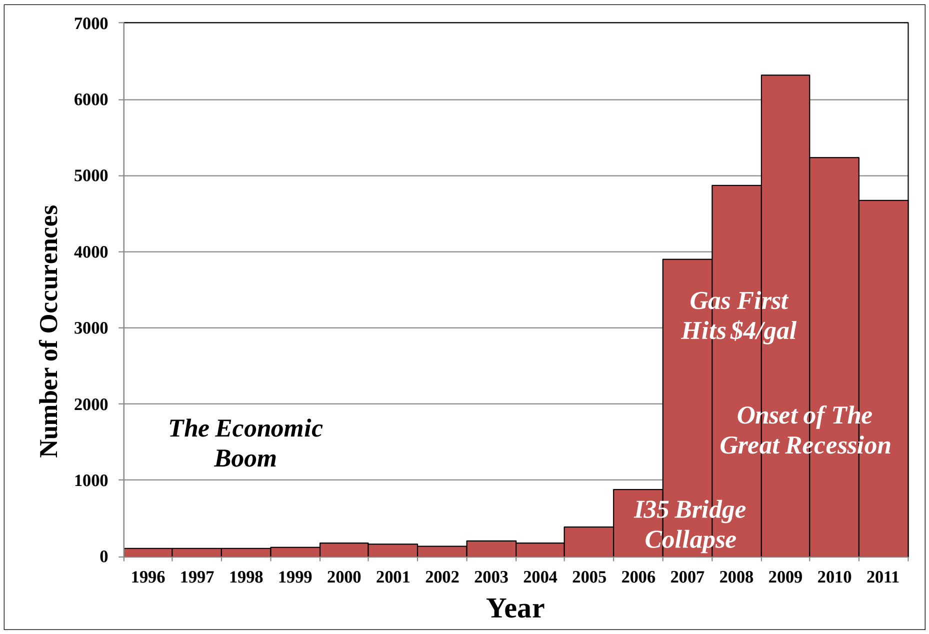
The word infrastructure is in vogue with the American body politic. In the 2011 State of the Union address, President Obama lamented, “Our infrastructure used to be the best, but our lead has slipped... Countries in Europe and Russia invest more in their roads and railways than we do. China is building faster trains and newer airports. Meanwhile, when our own engineers graded our Nation's infrastructure, they gave us a D” (Obama 2011). In his 2010 address, the president stressed the importance of keeping pace with China, Germany, and India in providing infrastructure to support economic development. Across the spectrum of American politics, from local to federal, there is an emerging consensus about the need for greater focus on the renovation and creation of infrastructure. Further, the broad and urgent issues of energy, infrastructure (particularly for electricity and transportation), and climate change have become inextricably linked as societies around the world discuss, disagree, debate, and make decisions about properly balancing the production and use of energy against quality of life and economic opportunity. A rough feel for the growing importance of this debate can be seen in a thumbnail analysis of the President’s State of the Union speeches, which represent some of the most carefully planned words in a given political year. Figure 2 shows the results of this analysis from 1975 through 2011; only the years listed were analyzed.

Figure 2. Mentions of "infrastructure" by U.S. presidents in their State of the Union addresses (Klosky, Katalenich and Hart 2012).



The dramatic increase in the use of infrastructure-related terms is not limited to presidential State of the Union addresses. Newspapers and print publications have followed suit, as shown in Figure 3. Drivers of this increase include public information efforts of organizations like ASCE, the World Economic Forum (WEF), and the U.S. Chamber of Commerce as well has high-profile failures of various infrastructure elements, often occurring for different reasons.

Figure 3. Occurrences of the word "infrastructure" in major print publications (Klosky, Katalenich and Hart 2012).



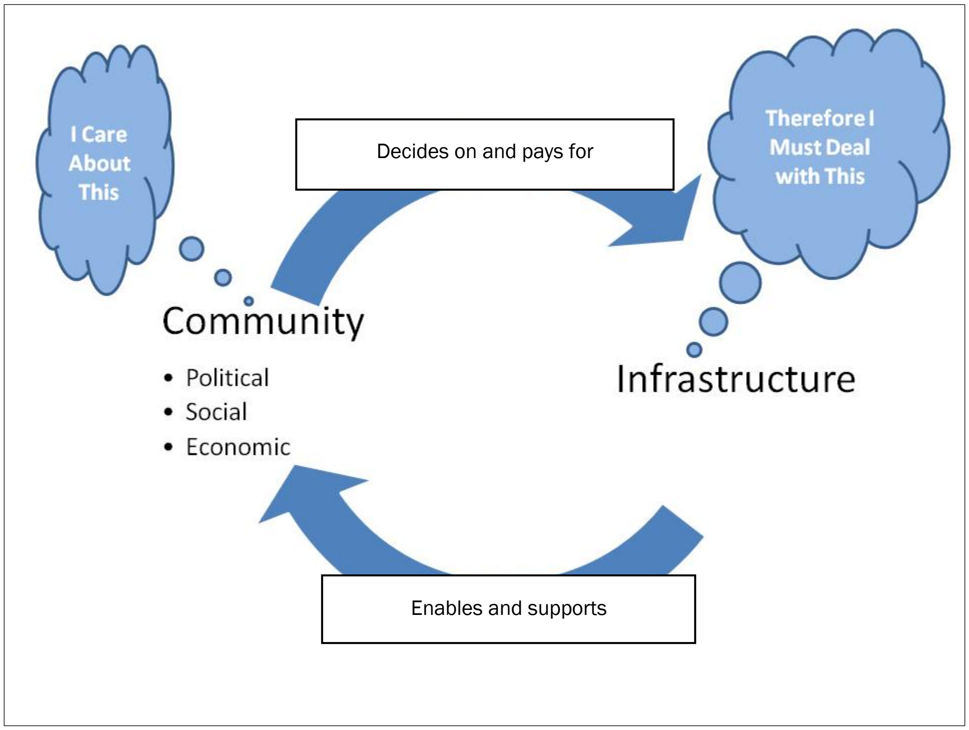
2.2.1 Infrastructure supports society; society supports infrastructure

An often difficult-to-measure relationship is the interdependency of infrastructure with the society it serves. Arguably, the direct effects of a failure in infrastructure are a technical problem. However, a more ambiguous challenge is measuring the tertiary political, economic and social effects that such an event creates. As society has modernized the interdependencies of communities have become increasingly interdependent and are illustrated in the following statement from the report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse Attack (Foster 2004, vol. 1, p. 2):

> "...the U.S. has developed more than most other nations as a modern society heavily dependent on electronics, telecommunications, energy, information networks and a rich set of financial and transportation systems that leverage modern technology. This asymmetry is a source of substantial economic, industrial and societal advantages, but it creates vulnerabilities and critical interdependencies that are potentially disastrous to the United States."

A society is inextricably linked with the infrastructure that supports it. Thus the social, political, and economic structure of a society can magnify or mitigate the effects of a failure in infrastructure and vice versa. This relationship can be visualized in Figure 4, and the sections that follow demonstrate this interdependency through the effects that recent disasters have had on the surrounding communities.

Figure 4. Interdependency of community and infrastructure.



Political impacts of Hurricane Katrina

Political ripple effects from a catastrophic failure of infrastructure can be illustrated by the aftermath of Hurricane Katrina which first made landfall on 29 August 2005. According to Dr. Robert Miller of National Defense University, “Simultaneous failures [of infrastructures] far exceeded the experience base and available resources of public officials and led to a partial or complete breakdown in command and control and public order” (Miller 2006). The immediate effects of these infrastructure failures during the response and recovery phases degraded the ability of officials to keep up with events and direct recovery efforts (Miller 2006). However, a more far-reaching and still-lingering effect is on public confidence. The lack of authoritative and believable information from public officials reduced the government’s ability to maintain public order immediately following (ibid.). Arguably, the feeling of dislocation and lack of public trust still affects the region and has forever changed the way in which information infrastructure is managed following catastrophic events.

Social impacts of Hurricane Katrina

D. A. Swanson, et al. (n.d.) presents a significant argument about how a catastrophic loss in the housing infrastructure following Hurricane Katrina affected the social fabric of the community. Housing losses over the 90,000 sq mi. area affected resulted in the fragmentation of the regional social networks of schools, churches, families and neighborhoods (Chappell et al. 2007). This fragmentation limited the recovery and long-term restoration of the community by increasing social vulnerability.* Vulnerabilities to the social fabric arise from both personal and physical attributes. Personal attributes may include: socio-economic status, employment, disabilities, and age. Physical attributes may include: housing status/quality, or the availability of transportation (Swanson et al. n.d.). Years after Hurricane Katrina, these vulnerabilities are still evident in these communities.

Economic effects of Hurricane Sandy

An example of the economic effects from a regional failure of infrastructure can be drawn from Hurricane Sandy's landfall in New York and New Jersey on 29 October 2012. Because of the economic activity concentrated in this area, Hurricane Sandy changed the economic patterns of the region, and those effects cascaded into the global economy. This section highlights some of those effects (Economics and Statistics Administration 2013).

- **Manufacturing**

  The immediate effects on 10,000 manufacturing firms that were affected by the storm included: repairing structural damage, draining flood waters, removing debris, and waiting for power, phone, and Internet to be restored. However, a more far-reaching and less-measurable economic effect of the storm was the effect on the global supply chain. Delays in the supply chain affect productivity of distributors and storage facilities outside the affected area.

* Social vulnerability refers to an inability of people, organizations and communities to withstand difficult events and situations.

- **Gaming industry**

  Although the economic loss of the Atlantic City casinos was estimated at $5 million per day, this economic effect was further magnified by strain on the information infrastructure. False media reports stating that the Atlantic boardwalk had washed away further magnified the negative effect on the overall regional economy.

- **Commercial trucking**

  Although an estimated 20% of the commercial trucking industry in the region was stalled due to the storm in October, trucking actually rebounded in the following month due to an influx in demand for reconstruction and repair material.

- **Automotive sales**

  Demand for the sale of autos increased due to the number of cars and trucks that had been totaled as a result of the storm.

- **Commercial and recreational fishing**

  Fishing, a major industry in the region, was also affected due to the storm. Capital assets (boats and equipment) were generally insured and did not create as much of an effect as the loss in economic activity. Most of the loss was concentrated at the food processing node. Total aggregate effects for the region are estimated at over $160 million and $33 million for recreational and commercial fishing respectively.

Communities collectively make decisions about, fund, and build the infrastructures that then support them. The way a community is organized—both physically and socially—will mitigate or magnify the consequences of an infrastructure failure. The resulting political, social and economic consequences are often hard to measure. Thus to protect the communities, the infrastructures that serve them must be planned and maintained with a clear vision of the future. This planning is necessary to avoid cascading failures which could be possible from neglect or poor understanding of these dependencies.

2.3 National aspirations for infrastructure

The aspirations of the nation for its infrastructure are often expressed in political and social discourse, the quantity and quality of which has been described above and in the publications of professional organizations. “America 2050,” an initiative of the Regional Plan Association, proposed a vision for a national plan for infrastructure focused on water, energy, and transportation (Regional Plan Association 2008). The ASCE has published their “Report Card on America’s Infrastructure” since 1988. More recently, ASCE began publishing a series of pamphlets titled *Failure to Act* which, for different infrastructure sectors, detail the investment required to prevent further infrastructure deterioration and economic loss. Additionally, the National Academy of Engineering (NAE) has articulated 14 “Grand Challenges” for engineering in the 21st century. Six of these challenges are directly related to infrastructure: (1) make solar energy economical, (2) provide energy from fusion, (3) develop carbon sequestration methods, (4) manage the nitrogen cycle, (5) provide access to clean water, and (6) restore and improve urban infrastructure. These professional organizations recognize that we cannot focus solely on the “things” of infrastructure; we must also develop the next generation of infrastructure engineers and leaders.

Over the past 10 years, national professional engineering societies have attempted to envision the future of the profession, to describe the engineer of the future, and to provide guidance for developing the profession that the society of the future will need. In one of the earliest of these works, In *The Engineer of 2020*, NAE describes how engineers will have to solve technical problems in a social-political-economic context that includes issues of sustainability, changing demographics, security, emerging technologies, and increased urbanization (NAE 2004). This complex context is compounded by a professional context marked by increased business and operational complexity, multi-disciplinary teamwork, requirements for advanced technical knowledge, and a global marketplace. To operate within these contexts, the NAE aspires to develop engineers who are creative and innovative in forming and leading interdisciplinary teams to solve complex problems at the intersection of engineering, business, policy, and social needs. NAE further aspires to engineers moving beyond traditional technical fields and aspiring to “assum[ing] leadership positions from which they can serve as positive influences in the making of public policy and in the administration of government and industry” (NAE 2004). The

NAE report asserts that theory and calculations remain necessary for success as an engineer, but by 2020, they will no longer be sufficient.

Similarly, the ASCE recognized that the infrastructure of the future will require a transformation in the role and development of engineering professionals. In *The Vision for Civil Engineering in 2025*, the ASCE envisions that "civil engineers will serve as master builders, environmental stewards, innovators and integrators, managers of risk and uncertainty, and leaders in shaping public policy." (ASCE 2007). The first of these roles is a traditional role of civil engineers and one at which the profession excels; the remainder are not. Although engineers are typically comfortable discussing technical matters with other engineers, they are generally underprepared for discussing complex ideas with the general public or engaging in the multidisciplinary problem solving required for environmental stewardship, innovation, risk management, and public policy. To address this deficiency, the ASCE included two new and three modified outcomes in its second edition of the *Civil Engineering Body of Knowledge for the 21st Century* (abbreviated as BOK2), as listed below (ASCE 2008).

- Outcome 2: Natural Sciences (new)
- Outcome 17: Public Policy (new)
- Outcome 12: Risk and Uncertainty (separated for increased emphasis)
- Outcome 18: Business and Public Administration (separated for increased emphasis)
- Outcome 22: Attitudes (separated for increased emphasis)

The ASCE further recognizes the need to develop new ways of thinking about emerging problems in *Guiding Principles for the Nation's Critical Infrastructure.* This document articulates four principles to inform the nation's approach to critical infrastructure issues, as listed below.

- Quantify, communicate, and manage risk.
- Employ an integrated systems approach.
- Exercise sound leadership, management, and stewardship in decision-making processes.
- Adapt critical infrastructure in response to dynamic conditions & practice.

It is easy to map these principles to the outcomes of BOK2, especially the new and revised outcomes highlighted above; it is also easy to see that the outcomes do not look like "traditional" civil engineering. Instead, they are a further recognition that the engineers of the future must augment traditional engineering skills with a conceptual framework that includes and accounts for the social, economic, and policy aspects of the problems being faced.

In summary, these professional organizations are calling for both a rejuvenated and transformed infrastructure and a new breed of engineering and societal leaders to effect this transformation.

2.4 Infrastructure and military operations

2.4.1 Infrastructure targeting in Iraq

Bombing The Al Fatah Bridge located between Kirkuk and Baiji, Iraq, is an example of failing to completely understand the impact of infrastructure elements on all phases of military operations. While the decision to destroy the bridge made tactical sense during combat operations of Phases II and III, (the military joint operating variable; refer to Figure 1), the resulting costs, difficulties, and delays in restoring oil flows greatly complicated the restoration of society during Phases IV and V (the social, political, and economic joint operating variables; refer to Figure 1), as detailed below.

During the 2003 invasion of Iraq, Coalition forces bombed the al-Fatah bridge over the Tigris River as a means of securing the right flank of the 4th Infantry Division's (ID's) maneuver from Baghdad to Mosul to link up with the 101st Airborne. The bridge was destroyed to deny an avenue of approach into the 4th ID's flank by two Republican Guard armored divisions located in Kirkuk. While destroying the bridge eliminated the avenue of approach, it also severed the 15 oil and gas pipelines that connected the production fields of Kurdistan to Baiji, Iraq's largest refinery, and subsequently to the Iraq-Turkey export pipeline. Shortly after the end of major combat, some oil flow from Kirkuk to Baiji was restored using an older, abandoned pipeline, but both the quantity and quality of the flow was greatly diminished. Additionally, no refined petroleum products were returned from Baiji to Kirkuk via this temporary pipeline (Hanus 2012).

The initial restoration plan called for a $5 million replacement bridge with pipelines running on the bridge. When this project was canceled in favor of higher-priority bridges in other locations, a $75.7 million project began for routing the pipelines under the river via a horizontal directional drilling. This project failed due to unsuitable soil conditions, a fact which had been identified in a site geotechnical report prior to the start of construction. Over three years after the bridge was destroyed, oil flow was fully restored by a $29.7 million cut-and-cover pipeline installation project.

What was the economic value of the destruction of the Al Fatah Bridge's pipeline? In 2003–2004, oil production in the Kirkuk region was 500,000 barrels per day (Hanus 2012), and the typical price of oil for 2004 was $40 per barrel (U.S. Energy Information Administration 2013). This means the economic value of the bridge was $20 million per day, $7.3 billion per year, or over $22 billion for the more than three years the pipelines were out of proper service.

2.4.2 Target, weapon, or asset?

Both historical and current analyses show that from a military perspective, infrastructure can be viewed as a target to be attacked, a weapon to be used, or an asset to be protected. A traditional approach to combat operations is to deprive the enemy of assets such as soldiers, tanks, fuel, transportation, and in doing so, degrade the enemy's combat effectiveness. For example, a commander might want to destroy a railway bridge to prevent the enemy from shifting forces rapidly between fronts. In this case, the problem becomes how best to destroy the bridge. Alternatively, a commander (or a terrorist) may attack an infrastructure item for the effect that its destruction will cause. A terrorist may attack a train, for example, not to destroy the train but to cause a release of the chemicals carried by the train thereby causing widespread panic, death, and economic disruption.

The speed of current combat operations is now measured in days or weeks, which means the transition to stability and establishment of civil authority also occurs more rapidly than in the past. As such, commanders considering the destruction of an infrastructure asset to support combat operations now must simultaneously consider the impact of this destruction on the stability operation that will follow next week. Destroying a purely military asset like a tank, a soldier, or a plane affects only the military variable. Destroying, or failing to protect, an infrastructure asset can impact political, social, and economic variables both immediately and for years into the future. As a result, commanders in today's complex environments must view infrastructure simultaneously as target, asset, and weapon and consider the effects from each perspective.

2.4.3 Infrastructure reconstruction in Iraq as reported by the Special Inspector General for Iraq Reconstruction

The U.S. government expended over $11 billion on infrastructure reconstruction in Iraq (SIGIR 2013, 70). A Special Inspector General for Iraq Reconstruction (SIGIR) was established, and while the office went through several names and organizational structures, the end-state was the same in that the U.S. government wanted to know if the efforts and funds expended were effective.

All infrastructure projects require leadership; in the case of Iraq, U.S. and Iraqi leadership were involved to varying degrees with the projects. The leadership is not directly involved in executing the projects and programs, although they make decisions on the programs that lead to the projects. They want to enact programs that will meet the needs of the society through the projects that are executed. The primary means for leaders to influence these programs is through political and financial actions related to the programs and projects.

The following is a brief summary of the final report from the SIGIR that takes a comprehensive look back at the effectiveness of the Iraqi reconstruction efforts.

Iraqi leadership perspective

From the Iraqi leadership perspective, U.S. efforts in infrastructure reconstruction had three main shortfalls. First, the Iraqi leaders felt that the United States failed to consult with Iraqi authorities when planning their reconstruction efforts (SIGIR 2013, 11). The United States could not hope to fully identify the needs of the Iraqi citizens if the leadership for those citizens was not incorporated into the planning process. This failure to engage key stakeholders had follow-on impacts on the United State’s inability to meet the technical and social requirements of the Iraqi people.

The second main shortfall of the U.S. efforts according to the Iraqi leadership was the lack of security and pervasiveness of corruption in the reconstruction process (ibid.). Since the United States did not ensure that security and corruption were addressed before projects began, the reconstruction efforts were doomed to have continuous issues.

The first two shortfalls lead to the final reflection by the Iraqi leadership on the third major shortfall: that the overall rebuilding effort had limited positive effects (ibid.). Without properly addressing program aspects required to set the foundation for infrastructure projects, the United States was viewed as executing a reconstruction effort that was not coordinated, was frustrated by security and corruption, and that eventually failed to adequately meet the needs of the society it was attempting to assist.

All 17 Iraqi leaders interviewed agreed that these three main shortfalls were inherent in the reconstruction efforts.

U.S. leadership perspective

U.S. leaders, from senators to generals, were not as focused as the Iraqis in what they felt were the primary issues with the reconstruction efforts. The diversity of opinion was drawn along the lines of what projects or oversight the U.S. leaders were involved with directly. While it becomes problematic to identify what the specific actions are that should have been adjusted, there are a few overarching aspects that were incorporated into the majority of the U.S. leaders' observations. Two aspects that were agreed on in general were: (1) organization of the reconstruction efforts suffered from a lack of direction, and (2) stakeholder engagement was severely lacking (SIGIR 2013, xii).

The lack of organization in preparing to begin executing infrastructure projects can be readily seen by the lack of security throughout the country as rebuilding was attempted, so that will not be further detailed here.

The lack of stakeholder engagement can be seen by a simple look at the timeline of the allocation of funds. The majority of the funds that were committed to infrastructure projects (nearly $12 billion U.S. dollars) were obligated by 2004 (SIGIR 2013, 58). In contrast, one of the key military leaders of the Iraq war, General Raymond Odierno, suggested that the Iraqi government was not functional enough to actively engage in the reconstruction efforts until as early as 2008 or as late as 2010. (ibid., 25) It is shocking that, while the U.S. government was still focused on establishing a functioning Iraqi government, it had already allocated most of the funds to infrastructure reconstruction. The allocation of funds thus occurred

4 years before the security situation allowed the Iraqi government to be functional enough to be involved in the process. (ibid., xii).

Figure 5 is an excerpt from the SIGIR report that details how the lack of stakeholder engagement led to ineffective infrastructure projects.

Figure 5. Excerpt from the SIGIR report on project waste (SIGIR 2013, 17).

SIGIR PA-08-138 and Audit 08-019

Khan Bani Sa'ad Prison: Waste in the Desert

Years of neglect, war damage, and looting left Diyala province's prisons in deplorable condition. In May 2004, the CPA awarded Parsons Delaware an $80 million task order to build the Khan Bani Sa'ad Prison, which would add 3,600 beds to the province's correctional capacity.

In February 2006, three months after the scheduled completion date, Parsons submitted notification that its new projected completion target was September 2008—a 990-day schedule slippage. In June 2006, the U.S. government terminated the contract for "failure to make sufficient progress on the project" and "massive cost overruns."

Still believing the prison was wanted by the Iraqi Ministry of Justice, reconstruction managers awarded three successor contracts to complete the work. In June 2007, the U.S. government terminated all work on the project for convenience, citing security issues.

At the time of termination, the United States had spent almost $40 million, but no building was complete. Two months later, USACE unilaterally transferred the unfinished project to the GOI even though Ministry of Justice officials told USACE they did not plan to "complete, occupy, or provide security for" the poorly and partially constructed facility.

SIGIR visited the site in June 2008, finding it neither secured nor occupied by the GOI. SIGIR's assessment documented poor-quality workmanship by Parsons, including many potentially dangerous conditions. Several sections were recommended for demolition. The site still sits dormant in Diyala and apparently will never be used.

The Khan Bani Sa'ad Prison was abandoned after the United States spent almost $40 million on it.

A final aspect that from the leaders' perspective led to a disconnect between the Iraqi and U.S. governments, was that the U.S. government measured success solely on U.S. dollars spent. The U.S. leadership's thinking was that if large amounts of money were being spent, then the reconstruction program was effective. As shown by numerous SIGIR audits, this thinking led to vast amounts of resources being mismanaged, and that mismanagement contributed to the perception of corruption (SIGIR 2013, x).

Change in strategic-level focus

Infrastructure projects continually interact with and are influenced by factors that go beyond the projects or even the programs. To understand how that interaction happens, it is important to look at how the goals of the U.S. government changed during the course of Iraqi reconstruction efforts.

Following the invasion of Iraq, the initial focus of the U.S. government was to fix the Iraqi oil industry and then remove the military from the Iraq in a rapid manner (SIGIR 2013, 71). This sentiment was captured by then Secretary of Defense Donald Rumsfeld in early 2003 when he said, “if you think we’re going to spend a billion dollars of our money over there, you are sadly mistaken (ibid., 72).” With the focus on merely restoring the oil infrastructure that prevailed before the war started, the USACE awarded a non-competitive contract to KBR* on 8 March 2003 to “restore and operate Iraq’s oil infrastructure.” This contract was “[t]he largest reconstruction contract for Iraq’s rebuilding and the largest known sole-source contract in U.S. history” (ibid., 84). The timing of that contract is important. On 8 March 2003, U.S. and other coalition forces were still in Kuwait. The contract was awarded prior to U.S. forces having the ability to assess how well the Iraqi infrastructure was meeting the needs of their society. This effort to rush the process of infrastructure development became a continuous theme throughout the Iraqi reconstruction efforts.

Following the fall of Saddam Hussein’s regime, USACE immediately set about assessing the state of Iraqi infrastructure. While the SIGIR report does not detail the specifics of what that USACE assessment entailed, it does detail that the assessment showed more was required than just focusing on the Iraqi oil infrastructure. This assessment directly led to the establishment of the Coalition Provisional Authority (CPA), which was established to oversee the initial funds of $2.475 billion allocated to the Iraq Relief and Reconstruction Fund (IRRF). With that allocation, the debate between a policy of “liberate and leave” or “occupy and rebuild” was officially ended. President Bush argued that these funds were “essential to secure the transition to self-government and to create conditions for economic growth and investment” (SIGIR 2013, 72). It had been decided that the United States would attempt to rebuild the Iraqi infrastructure. Unfortunately, many of the tactics that were used by the U.S. military during the invasion caused more damage to that infrastructure, but at least after the decision was made, restoration could begin.

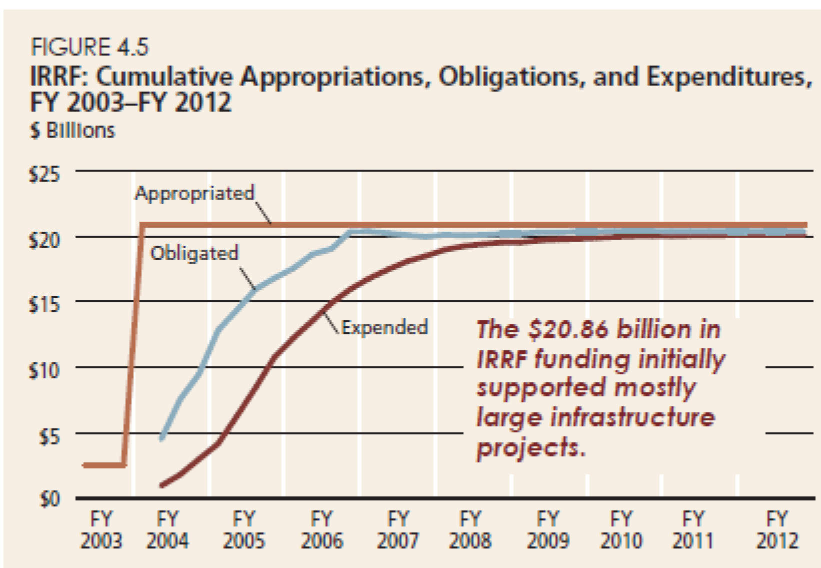
* Kellogg, Brown and Root is a global engineering, construction service company headquartered in Houston, Texas.

With this new focus, the U.S. government set about fixing the Iraqi infrastructure as quickly as possible. The IRRF funds were fully appropriated by FY 2004, and obligations of the funds were completed by FY 2006 (see Figure 6). However, the ability of the U.S. government to appropriate, allocate, and engage Iraqi stakeholders was severely limited. The United States was spending a large amount of money but did not know if those funds were spent on the right projects.

In an attempt to focus the hurried efforts to allocate U.S. funds, the CPA issued an overarching set of priorities. The basis for these priorities was a focus on "delivery of basic services." Those services included (SIGIR 2013, 75):

- reconstituting the power infrastructure,
- improving water-resource management,
- ensuring food security,
- improving health care—quality and access,
- rehabilitating key transport infrastructure,
- improving education and housing—quality and access, and
- reconstructing the telecommunications system.

Figure 6. IRRF funding status (SIGIR 2011, 58).



The reconstruction program attempted to follow those overarching priorities, yet it still ran into issues at the project level. A closer look some specific sectors of Iraqi infrastructure can show how a more focused effort on delivering the functions of an infrastructure could have led to a more effective reconstruction program.

Electrical infrastructure

The electrical infrastructure projects initially focused solely on producing more megawatts and ensuring that the ability to measure the electricity produced was readily available. By November 2003, the CPA had a list of 110 high-priority projects that were required for a functioning Iraqi electrical grid. Those projects focused on "generation, transmission and distribution projects" (SIGIR 2013, 76). What was lacking was the coordination of the delivery of electricity to the users. Electricity must be generated in real time to meet the demand being placed on the system by the users. Regardless of how many megawatts were being produced, if delivery coordination was not in place, the electrical grid would not be able to serve Iraqi society. To further complicate matters, the demand on the electrical grid outpaced the increased generation capacity. Consequently, 80% of the responses to a survey in 2011 rated the electricity service as either "bad" or "very bad" and indicated the resources expending on the electrical infrastructure failed to deliver electricity at an adequate level (ibid., 78).

Combustion power plants require natural resources (oil or natural gas) to generate electricity. The electrical generation projects in Iraq focused on installing natural gas generators. Natural gas turbine generators would allow the Iraqis to make use of large natural gas reserves within their country. However, these facilities had the dual distinction of being "more technologically advanced than thermal plants and easier to construct" (SIGIR 2013, 77). The ease of construction made the projects easier for the U.S. contractors to show benefits from their efforts. That benefit, however, is contrasted by the need to give the Iraqis necessary training to operate the more advanced facilities. The focus on ease of construction while not keeping up with the training of the Iraqis led to long-term issues.

By design, these new plants required natural gas. With delays in the natural gas delivery, however, the plants were forced to use crude oil or low-grade fuel oil (see case study in Figure 7). This resulted in an inefficient set of electric plants that required assistance from outside contractors. It also required that the Iraqi government figure out how to solve the interdependency issues between natural gas and electricity, something that may or may not have been possible.

Figure 7. Excerpt from SIGIR report of selected electrical projects (SIGIR 2013, 78).

SIGIR PA-07-101 and PA-07-104

Shock and Audit: Inspecting an Electricity Plant

SIGIR assessed two large electricity projects in 2007. The projects planned to restore and expand generating capacity at the Qudas Power Plant in Baghdad. SIGIR inspections produced a number of "good news stories," and this was one, at least with regard to execution. The two projects were adequately designed and properly completed or progressing satisfactorily.

The Qudas work was an important part of the rebuilding program's strategic commitment to improve Iraq's electricity production. It involved the installation or rehabilitation of combustion turbines. These units run best when fueled by natural gas, of which Iraq has enormous reserves.

The country's gas infrastructure in 2003 was vastly underdeveloped. Thus, there was no choice but to burn crude oil or low-grade fuel oil in the combustion turbines at the Qudas plant. But this reduced the generating units' capacity, increased downtime, and limited long-term productivity. By late 2011, a solution appeared to be in the offing. The Ministry of Oil signed an agreement with Royal Dutch Shell to form a joint venture to capture and make productive use of natural gas from Iraq's southern fields. This opened the door to more efficient power plants, assuming the Ministries of Oil and Electricity could learn to work well together.

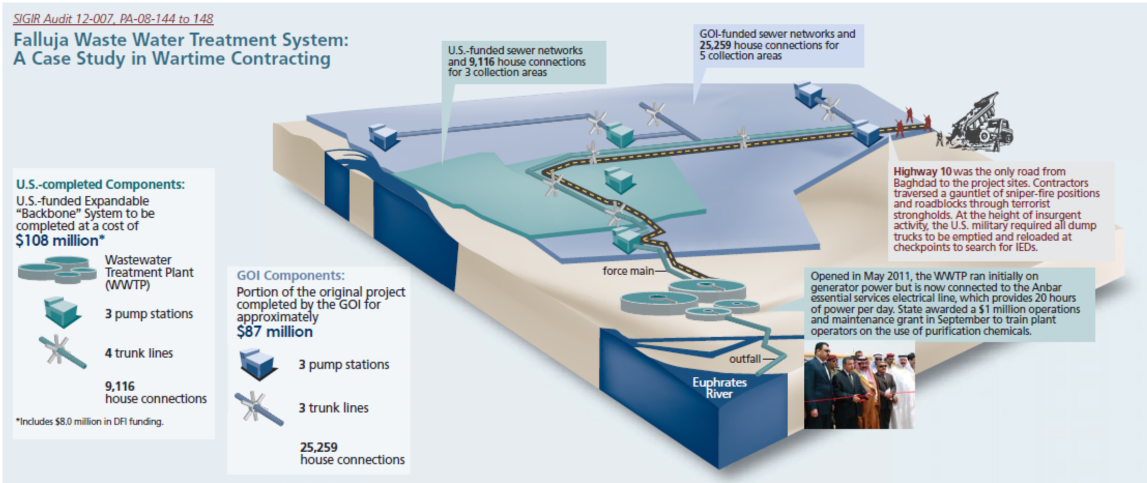
The United States spent more than $250 million restoring the Qudas Power Plant under several different projects. (USACE photo)

Water infrastructure

Figure 8 shows U.S. efforts and expenditures on the Fallujah Wastewater Treatment System. Like many projects in the water sector, this project initially seemed beneficial to the society that it served. However, issues arose during the transfer of some water systems to the Iraqis.

> After the United States turned over the large water projects to Iraqi control, reconstruction officials discovered that, in many cases, the Iraqis were not operating these projects properly. Shortfalls included equipment theft, badly trained staff, poor operations and maintenance practices, and inadequate supplies of electricity and treatment chemicals (SIGIR 2013, 81).

Figure 8. Fallujah wastewater treatment summary (SIGIR 2013, 82).



The failure to plan adequately for the impending transfer of the projects back to the Iraqis led to the eventual failure of those projects to deliver the intended services. Not all water sector projects suffered from these issues. In Ifraz Kamal Agha, the water treatment plant performed well, was expanded by Kurdish authorities, and was one of the most successful infrastructure projects in Iraq (SIGIR 2013, 79). The difference between that project and others was that the Iraqis were integrated into the project at an early time, resulting in proper training and transfer.

Also, as seen in Figure 8, many water projects required access to a viable transportation system—mainly, safe and secure roads. The lack of security on Highway 10 caused cost increases and delays, because the United States could not provide adequate security (SIGIR 2013, 82).

Oil and gas infrastructure

With the combined problems of: (a) the largest single-source contract being issued prior to U.S. forces seeing the state of the Iraqi oil infrastructure and (b) the single focus on fixing the oil and gas infrastructure from the outset of the reconstruction efforts, it would seem that the oil and gas infrastructure would have had the best opportunity to effectively meet the needs of the citizens.

In fact, the initial push to solely fix the oil and gas infrastructure ended up causing more waste than if it had been a lower priority. The initial push to fix the infrastructure caused the production goals to be met rather rapidly. By September 2003, the post-war production goals were being met. However, without a functioning infrastructure to serve the rest of the population's needs and to ensure that production could be exported, the oil and gas infrastructure became a favorite target of insurgents. The inability of the United States to defend the entire oil pipeline network allowed the insurgents to focus their attacks on the pipeline to disrupt production. Eventually, all of the critical pipelines from northern oil fields to the southern port of Ceyhan in Turkey had to be protected (SIGIR 2013, 84). Only this extreme measure allowed the oil infrastructure to function properly.

As previously discussed in Section 2.4.1 and shown in Figure 9, the Al-Fatah Bridge was bombed and subsequently destroyed by U.S. forces. In the targeting process, the failure to identify the interdependency between the transportation infrastructure and the oil and gas infrastructure resulted in achieving an immediate tactical effect but also causing severe problems moving crude oil out and refined petroleum into Kurdistan for over 3 years. All told, military actions caused $457 million of damage to the oil and gas infrastructure (SIGIR 2013, 84).

Figure 9. Impacts of bombing the Al Fatah Bridge (SIGIR 2013, 83).

SIGIR SA-05-001

Al-Fatah Pipe Dream

During the 2003 invasion, Coalition forces bombed al-Fatah Bridge in north-central Iraq, severing the 15 oil and gas pipelines it carried across the Tigris River. This damage cut off oil flows to the Bajii refinery, Iraq's largest. Repairing the pipelines was crucial to the recovery of Iraq's oil sector.

Originally estimated at $5 million, the al-Fatah project planned to repair the bridge and the pipelines. But the CPA and the Ministry of Oil decided instead to use horizontal directional drilling to re-route the pipelines under the river, which increased the estimated project costs to $28 million.

An initial study of the geological conditions beneath the river produced a recommendation against drilling because of the sandy soil. But horizontal drilling work pressed ahead anyway, with tens of millions of dollars wasted on churning sand, as attempt after attempt to drill failed to make headway. The $75.7 million in DFI funds allocated to the project was spent accomplishing just 28% of the project's scope. Ultimately, the drilling plan was abandoned, with the bridge and its pipelines repaired under a new $29.7 million IRRF-funded contract that the U.S. government awarded to Parsons Iraq Joint Venture. Because of the nature of the original contract, the government was unable to recover any of the money wasted on this project.

Coalition bombing damaged al-Fatah Bridge in 2003.

Transportation infrastructure

Oil and gas was not the only infrastructure that relied on the transportation system. As previously detailed, the reconstruction efforts for the Fallujah Wastewater Treatment facilities required a secure transportation network, a condition not satisfied because the insurgent-interdicted Highway 10 was the only means to access may of the worksites. The oil and gas infrastructure could not export any of their goods through Iraqi ports due to the lack of maintenance of those ports. Consequently, single-point mooring systems were used, but those operated at only 50% of capacity. Eventually, the ports were dredged and became fully functional in 2010 (SIGIR 2013, 83–88). The overall impact on the reconstruction efforts severely limited the ability of the Iraqi government to be self-supporting.

The majority of funds that were spent on transportation were administered as Commander's Emergency Response Program (CERP) funds. These funds were many times administered at the Battalion level, which resulted in a lack of coordination of efforts for the reconstruction of the transportation infrastructure (SIGIR 2013, 87).

Most of the funds (90%) allocated to transportation were appropriated by September 2007. However, this date was one year before the earliest functioning date for the Iraqi government. This lack of date alignment made partnering with the Iraqi government on transportation projects impossible.

Communications infrastructure

One of the goals of the communications infrastructure projects was to "introduce advanced technologies." While cell-phone subscription did increase drastically, there is no mention of whether the advanced technologies of an Advanced First Responder Network, Consolidated Fiber Network, and the al-Mamoon Exchange and Communications Center actually met the needs of the Iraqi society. Iraq's telecommunications infrastructure remains one of the least developed in the region (SIGIR 2013, 86–89).

Security for infrastructure

All infrastructure projects require some level of security around the infrastructure that is attempting to serve the society. The final fix to allow reconstruction to progress was the establishment of security. Instead of trying to reconstruct the Iraqi infrastructure in an unsecure environment, the environment was secured specifically to allow reconstruction to happen. The Infrastructure Security Protection Program was established in 2006 and "sought to reduce the incidents of insurgent damage to the oil pipeline system, electrical distribution system, and other important infrastructure throughout Iraq" (SIGIR 2013, 100).

A corollary to that program was the well-known Sons of Iraq (SOI). One of the needs of the Iraqi society was employment, and the SOI program sought to employ potential insurgents to reconstruct the society and to keep them from fighting the reconstruction (Figure 10). With the implementation of the SOI program which coincided with the surge of U.S. forces, the resulting security improvements allowed infrastructure projects to be completed to serve the society.

Figure 10. SIGIR summary of Sons of Iraq program (SIGIR 2013, 100).

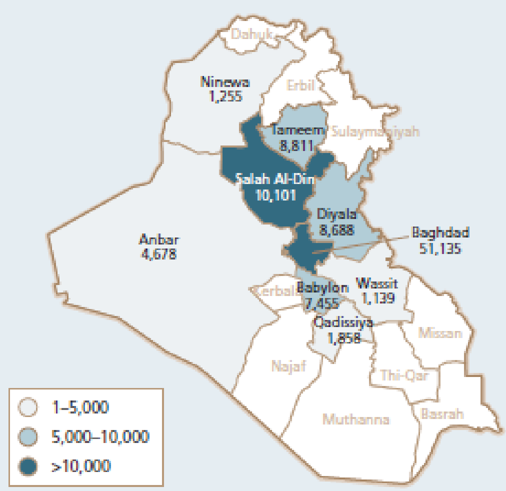
SIGIR Audit 11-010

Sons of Iraq: Work, Don't Fight

Insurgent attacks in 2006 spiked, particularly in western Iraq. While Sunni tribes supported the growth of al-Qaeda in Iraq—the chief catalyst of renewed violence—attacks began to hit local citizens, particularly in Anbar province. This caused some Sunni leaders to seek cooperation with Coalition forces in what came to be called the "Anbar Awakening." DoD credited these leaders with helping to improve security in tribal areas.

To advance the Awakening, Multi-National Corps-Iraq began to award CERP contracts in June 2007 chiefly to employ Sunnis. The leaders agreed to keep their people off the battlefield in exchange for CERP-funded jobs providing security for buildings, checkpoints, and neighborhoods.

This effort, known as the "Sons of Iraq" program, entailed approximately 780 separate agreements calling for the stationing of almost 100,000 in 9 provinces across Iraq. The sheer number of agreements and personnel involved made this the largest CERP program in Iraq. SIGIR noted in its review of the SOI program that the contracting process, which spent $370 million in CERP funds, was far from transparent. Financial controls were weak, program managers could not tell whether SOI members received their U.S.-funded salaries, and Defense was unable to provide any evaluations of the program's outcomes.



The SIGIR final report is entitled "Learning from Iraq" and is dedicated "For all those lost in Iraq." In Iraq, some programs and projects went right, and some went wrong. We owe it to those lost in Iraq to learn the lessons of both.

2.4.4 Infrastructure reconstruction in Afghanistan as reported by SIGAR

The Special Inspector General for Afghanistan Reconstruction (SIGAR) has not published a final report, so compiled information is not as readily available as it was from the SIGIR comments. In reviewing the documents of the ongoing reconstruction in Afghanistan from the SIGAR, however, the same issues that were identified in the Iraqi reconstruction come to light again. Those issues include: water and power projects are fraught with corruption, coordination issues occur, and there is an ongoing debate as to whether Afghan needs are actually being met. (SIGAR 2010, 2012a, and 2013a)

What this section will do, instead of capturing all the lessons learned as was done with Iraqi reconstruction, is to highlight how a few of the Afghan projects demonstrate similar issues to those identified in Iraq.

Police station infrastructure

In a report dated 24 January 2013, the SIGAR identified that the Kunduz Afghan National Police Provincial Headquarters was not projected to be functional in the future. The station suffered from a lack of stable electrical supply. The only power source available was a single diesel generator. Having only the single generator ensured that the station would be without power for at least some of the time because of routine maintenance and refueling of the generator. The police station also relied on electricity to operate a sewage lift station. Thus, the lack of redundancy in the power supply could lead to serious sanitation issues. Finally, the station did not have personnel that were trained in the operation of the generator and sewage system. Essentially the project had been turned over to the Afghans with no training on the operation of the building (SIGAR 2013b).

In a report dated 29 January 2013, the SIGAR identified similar issues at the Imam Sahib Border Police Company Headquarters. The headquarters had no backup electrical system. Additionally, the headquarters was designed to accommodate 175 personnel. The current occupancy, at the time of the report, was 12 personnel. The investigation reported that there were no known plans to have the other 163 personnel stationed at the headquarters. Since the Afghan police force was using less than ten percent of the station's capacity, it is unclear if the station needed to be built to the size that it was. Similar to the Kunduz headquarters, there were no trained personnel at the station to operate the electrical, water, fuel or HVAC system (SIGAR 2013c).

The lack of trained personnel at both headquarters was identified to be an unsurprising fact. The contracts that were on file for both stations showed no allocation or requirement for any operations and maintenance contracts or training. The stations were built, but the transfer of the stations to the Afghans with the necessary skills to operate them was not considered, or if it was considered, it was not properly accounted for in the contract documents (SIGAR 2013b, 2013c).

Power equipment infrastructure

In a report dated 18 December 2012, SIGAR identified $12.8 million U.S. of power utility equipment that was not being used. The equipment was purchased with the intent to immediately transfer it to Da Afghanistan Breshna Sherkat (DABS), the national power utility. The equipment was purchased rapidly to meet objectives in support of counterinsurgency operations (the specific objectives were not listed in the report and have not been researched by the authors). None of the procuring agencies between procuring agencies about what was required to conduct a final transfer led to the equipment not being used (SIGAR 2012b).

Medical facility infrastructure

The CERP in Afghanistan met with the same varying success as the Iraqi version. A brief comparison between two medical clinics highlights the difference.

The SIGAR reported on 17 April 2013 that the Qala-I-Muslim Medical Clinic was serving the community well. The facility was reporting large numbers of patients being seen (1,565 outpatient consultations, 63 prenatal patients, and 63 newborn deliveries in 19 months of service) and was being well-maintained. While it is difficult to ascertain all of the reasons that this project went well, it should be noted that the local elders placed a large emphasis on this project. One elder even donated the land that the clinic was built on. The clinic was built to expand the capabilities of an already-existing storefront clinic in the village. The drawback cited in the report was there was no documentation on the quality of the construction (SIGAR 2013d).

The SIGAR also reported on 30 October 2013 that the Walayatti Medical Clinic had never been used. A critical generator and two water heaters were not present. Two rooms for latrines with two stalls each, which would allow simultaneous use by both genders, had been modified to one room with four stalls. Documentation of the means and methods of construction also was missing from the construction documents. While the Afghan Ministry of Public Health (MOPH) had signed an agreement to staff and equip the clinic upon transfer, the officials denied any knowledge of such an agreement (SIGAR 2013e).

The details are unclear as to why Qala-I-Muslim was fully functioning while Walayatti was sitting completely unused. The is a stark discrepancy in the productivity of two projects which were both administered under the CERP and had the same documentation issues.

Summary

The SIGAR oversaw reconstruction that was inherently starting from a different point than the reconstruction that the SIGIR oversaw. The Iraqi infrastructure was simply more developed before U.S. forces attempted to reconstruct it. The issues that arose from police and medical facilities may have been seen in Iraq as well, if Iraq had been on the same (lower) level of infrastructure development as Afghanistan. The correlation between the two countries is eerily similar in that the reconstruction projects failed to engage stakeholders and to consider the eventual transfer of the projects.

2.5 Infrastructure in Army doctrine

The Army's need for understanding infrastructure is articulated in its capstone doctrine. The two major shifts in the Army's understanding of infrastructure occurred in 1991 and 2006. In the 1970s and 1980s, the Army was primarily located in Europe and expected to fight in Europe. After Operation Desert Storm and the fall of the Soviet Union in 1991, the Army understood that it would first deploy to parts unknown and then fight. As such, the Army's capstone field manuals of 1993–2001 made extensive references to infrastructure, but always in the context of deployment (e.g., intermediate staging bases, aerial ports of embarkation, seaports of debarkation). Combat operations in Afghanistan and Iraq from 2001–2005 along with Hurricanes Katrina, Rita, and Wilma in 2005, demonstrated that infrastructure was both a condition of the Army's operational environment and an operational tool for counterinsurgency and re-establishing civil society. Infrastructure was thus introduced as a joint operating variable, and the Army included in their doctrinal responsibilities the need to protect and restore infrastructure. Appendix A contains the historical evolution of infrastructure in doctrine.

The Army's primary contribution to Joint Operations is landpower, "the ability—by threat, force, or occupation—to gain, sustain, and exploit control over land, resources, and people" (U.S. Army 2012a). Landpower includes, in addition to imposing our Nation's will by force when necessary, the ability to:

- engage to influence, shape, prevent, and deter in an operational environment;
- establish and maintain a stable environment that sets the conditions for political and economic development;
- address the consequences of catastrophic events—both natural and man-made—to restore infrastructure and reestablish basic civil services; and
- support and provide a base from which joint forces can influence and dominate the air and maritime domains of an operational environment.

An analysis of these abilities reveals that the first and fourth are often accomplished through infrastructure, the second sits squarely upon the infrastructure of the host nation (recall Carlini's definition in Section 1.1.1), and the third explicitly assigns responsibility for infrastructure restoration to the Army.

In the operation concept of Unified Land Operations, the Army demonstrates its two core competencies, combined arm maneuver and wide area security through *decisive action* defined as "the continuous, simultaneous combinations of offensive, defensive, and stability or defense support of civil authorities tasks" (U.S. Army 2012a). Typical decisive action tasks and purposes are show in Figure 11. The green highlights are tasks and purposes that imply infrastructure. For example, the restoration of many essential services like electricity, gas, water, and sewage is achieved through infrastructure. The yellow highlights are task and purposes that are explicitly infrastructure based.

As the Army moves forward with implementing the lessons of Iraq and Afghanistan in future doctrine, it is clear that infrastructure is both a characteristic of the operating environment and a tool to be used for mission accomplishment. Furthermore, the doctrine implies that the Army can identify and assess infrastructure prior to accomplishing the Army's specified tasks of protecting, restoring, and developing infrastructure. Although the capstone doctrine is written, implementing doctrine and professional military education programs do not exist for infrastructure.

Figure 11. Tasks of decisive action from ADRP 3-0 (U.S. Army 2012a).

Offense	***Defense***
Tasks:	**Tasks:**
• Movement to contact • Attack • Exploitation • Pursuit	• Mobile defense • Area defense • Retrograde
Purposes:	**Purposes:**
• Dislocate, isolate, disrupt, and destroy enemy forces • Seize key terrain • Deprive the enemy of resources • Develop intelligence • Deceive and divert the enemy • Create a secure environment for stability tasks	• Deter or defeat enemy offense • Gain time • Achieve economy of force • Retain key terrain • Protect the populace, critical assets, and infrastructure • Develop intelligence
Stability	***Defense Support of Civil Authorities***
Tasks:	**Tasks:**
• Establish civil security (including security force assistance) • Establish civil control • Restore essential services • Support to governance • Support to economic and infrastructure development	• Provide support for domestic disasters • Provide support for domestic chemical, biological, radiological, and nuclear incidents • Provide support for domestic civilian law enforcement agencies • Provide other designated support
Purposes:	**Purposes:**
• Provide a secure environment • Secure land areas • Meet the critical needs of the populace • Gain support for host-nation government • Shape the environment for interagency and host-nation success	• Save lives • Restore essential services • Maintain or restore law and order • Protect infrastructure and property • Maintain or restore local government • Shape the environment for interagency success

2.6 Infrastructure and the nature of problems

One inescapable conclusion of studying infrastructure problems is that they are "different." This difference tends to appear when someone asks a question like, "We replaced the I-35 bridge in Minneapolis in about a year; why did it take us 10 years to replace this local bridge?" The speaker inherently has identified that there must be more to bridge building than technical requirements. This difference in time can be articulated in different problem classes found in literature.

2.6.1 Technical problems

Technical problems are characterized by a consensus on the nature of the problem, an ability to use metrics to evaluate options leading to an optimal solution, and a general agreement when the solution has been achieved (Rittel and Webber 1973). During the scientific and industrial revolutions, the engineering profession came into its own through its skill in solving the technical problems associated with those eras.

In the 20th century, many technical solutions began to detract from the quality of life they were intended to support. Toxic chemicals resulting from industrial production of consumer goods that people wanted resulted in toxic waste dumps that people did not want. This conflict between a social good such as a clean environment and a technological good such as manufacturing aluminum can gave rise to the idea of *social-technical problems* which, as the name implies, have a strong technological component with significant societal implications. These problems are characterized by layered networks where the immediate problem at hand requires a network representation, and this problem as a whole is also a node in a higher-level problem (Sussman 2010). These problems are so different in their nature that Professor Joseph Sussman of MIT argued for a new field of study in Sociotechnical Systems (Sussman 2012). Infrastructure problems are clearly social-technical problems: the problems and solutions are based in technology but are only undertaken in the service of society.

2.6.2 Wicked problems

Infrastructure problems can also be characterized as *wicked* after the concept of Rittel and Webber (1973). Rittel and Webber listed ten characteristics of *wicked problems* yet offered no formal definition of the term. Wicked problems can generally be characterized by a lack of agreement on problem definition, a lack of agreement on the evaluation metrics, a lack of agreement on potential acceptable solutions, and the inability to optimize to achieve the best solution. These externalities to the problem are compounded by the fact that every attempt to solve the wicked problem irreversibly changes the system in question and the problem itself—there are no Mulligans when it comes to wicked problems. Unlike technical problems, wicked problems are never solved; they are merely temporarily resolved.

2.6.3 Other problems and solutions

As we look into the future, technical problems have not gone away, but they have been joined by social-technical, wicked, and other problem characterizations such as complex-adaptive, complex-evolving. It is this recognition that has led the NAE and ASCE to challenge the engineering profession to take a leadership position in these problems. When one also considers that the solution to many technical problems can be commoditized and outsourced (Friedman 2006), it is imperative that our students are able to solve not only technical problems but also ones of the social-technical and wicked varieties.

2.7 Processes for problem solving

Since different problems are different by their very nature, it follows that different solution processes are required for different classes of problems. From this, the first step in problem solving may well be "Determine the nature of the problem and select an appropriate process to solve it." For example, a man who is a scientist and a husband will not approach the challenges of buying a twenty-fifth wedding anniversary gift for his wife and developing a neutralizing solution for the highly toxic XYZ molecule in the same manner, at least not if he wants a happy anniversary. This section describes a small sample set of problem-solving methodologies, the problems classes for which they are intended, and the inputs necessary to begin.

2.7.1 Technical problem-solving processes

Though they have been around since antiquity, technical problems and their solutions grew in direct proportion to industrialization. "How do we get the water out of the mine?"—a question answered by James Brindley at the Wet Earth Colliery (Wikipedia 2013). "How do we generate and use electricity?"—a question where the answer was begun by Thomas Edison and Nikola Tesla, and the search for the best solution continues. "How do we make a vehicle go further, faster, even to the moon?" These are questions still being answered by legions of scientist and engineers.

To address these questions, scientists and engineers use similar processes, as compiled by this report's authors in Table 1

Table 1. Scientific and engineering processes.

Scientific Process	Engineering Process
Propose a question	Define the problem
Propose a hypothesis	Determine facts and assumptions
Predict a result	Develop design alternatives
Plan and execute investigations	Evaluate design alternatives
Analyze and interpret data	Select the optimal design
Communicate the findings	Communicate the design

Both types of processes begin with a similar presumption—that agreement can exist in defining the issue at hand, the boundaries of the issues, the metrics for evaluations, and the solution. In short, it is possible to say, "That is the problem and this is the answer," and while people may not like either the problem or the answer, they can at least agree on it.

2.7.2 CLOIS

Complex, large-scale, integrated, open systems (CLOIS) are a class of systems in the social-technical domain for which traditional scientific/engineer problem solving processes are ill-suited. This is because a CLOIS possesses many subsystems, some human and some technical, that are nested in their behavior and complexity and often behave collectively in unpredictable or counterintuitive manners, even when a subsystem's behavior is well understood. To address this challenge, Dodder, Sussman, and McConnell (Dodder et al. 2004) proposed the CLOIS Process which they demonstrated using the transportation network of Mexico City.

The CLOIS process has three phases: *representation, design and evaluation,* and *implementation* which are detailed below.

1. *Representation* involves developing and understanding of the system's structure and relationships by using both diagrams and narratives for the purpose of understanding behavior. Because this type of system often exhibit layers of nested complexity, multiple representations are sometimes required. This phase also includes goal formation and envisioning the desired state of the system.
2. *Design and evaluation* determines performance metrics for systems and subsystems, valuation and prioritization of performance, and options leading to improved performance.
3. *Implementation* investigates how the performance enhancements are viewed by all parties, if and how the performance enhancements are implemented, conflicts and tensions resulting from implementation, and unintended consequences.

The twelve steps of a CLOIS process are shown in Figure 12. Note the highly iterative nature of the process with knowledge and understating gained in one step forcing a reevaluation and reforming of prior steps. The process relies heavily on graphical representations of system interactions and an example of this is shown in Figure 13.

The CLOIS approach builds on previous work done in systems approaches by attempting to represent the entire system—physical, social, political, economic, and institutional—and facilitate deeper understanding of behaviors which, in turn, leads to better solutions. The CLOIS analyst is provided with flexibility to balance detail and complexity based on time, funding, and information and cognitive limits. Finally, by providing both a step-by-step framework and analyst flexibility, the process strives to minimize omissions of critical perspectives, add rigor and structure to the analysis, and allow for creativity in investigation and solution.

Figure 12. Steps in a CLOIS process (Dodder et al. 2004).

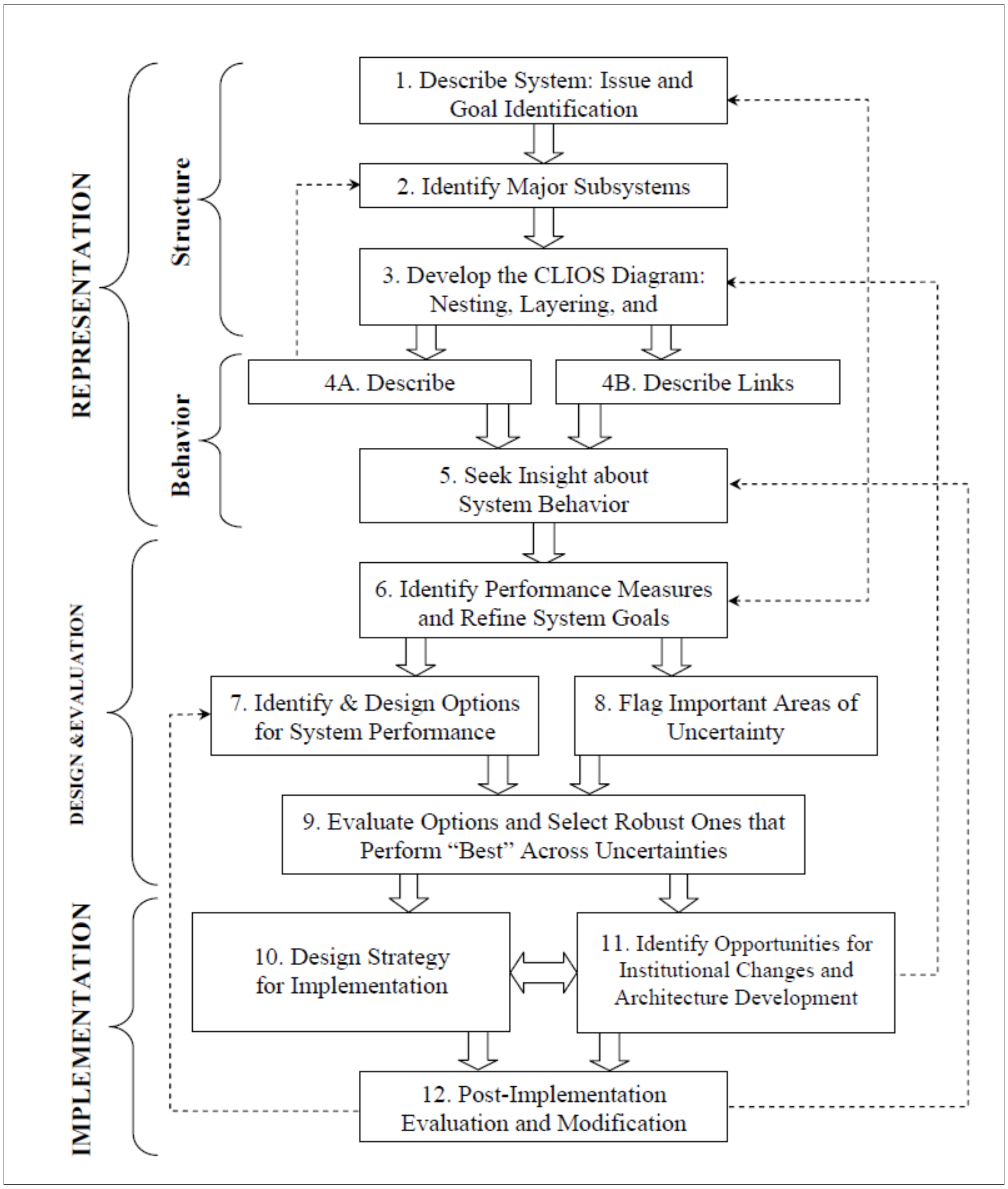
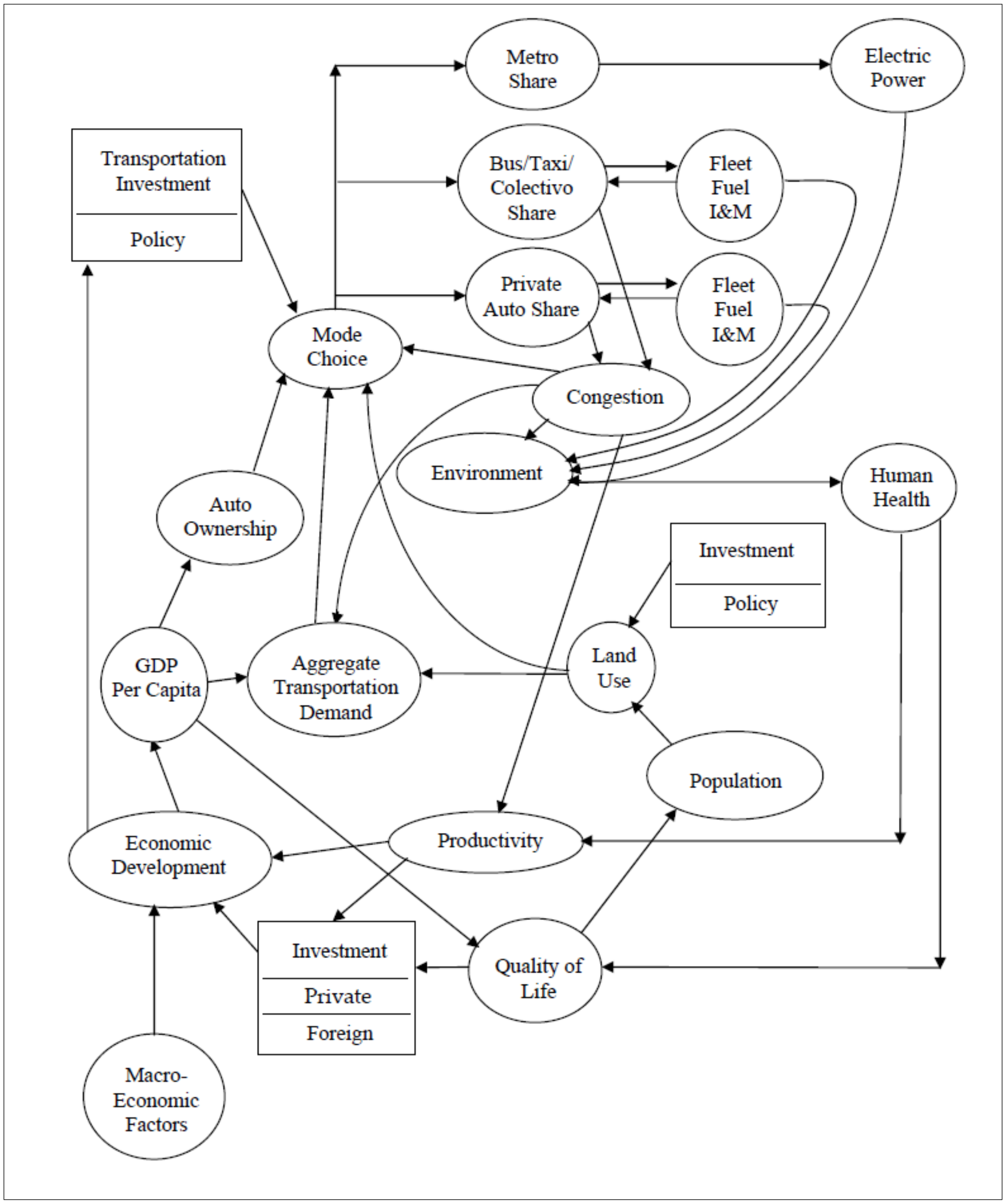


Figure 13. CLOIS process example sub-system rendering (Dodder et al. 2004).



2.7.3 Design thinking

The concept of *design* (or *design theory* or *design thinking* to some) traces its history to Herbert Simon in *The Sciences of the Artificial* (Simon 1968), and it is a methodology for understanding and thinking critically about complex, ill-structured problems and developing approaches to solve them. Design is focused on solutions to artificial (i.e., man-made) problems as opposed to natural problems. It is a solution-based approach that often begins with stating the desired end-state, as opposed to scientific and engineering methodologies which begin with the statement of the problem. Once an end-state is visualized, the designer seeks to understand the current conditions, and a problem set emerges as the designer contemplates how to transform the current state into the desired future state. In design, problem resolution and problem framing are concurrent, interdependent activities.

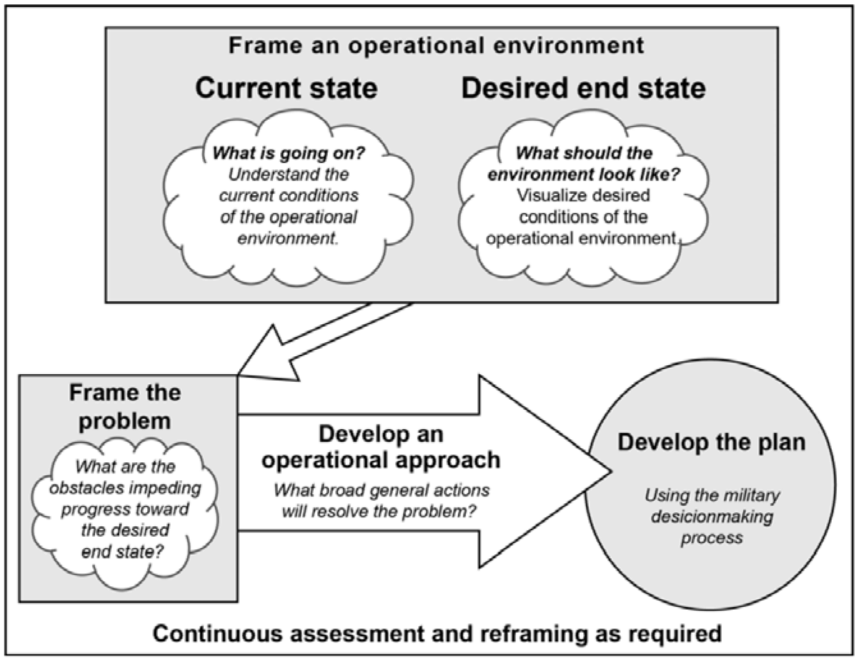
While the concept or philosophy of design has proven effective in leading to innovations such as the Herman Miller Aeron chair and the iPad, it must be articulated in terms of a methodology which can be taught to many before it can be employed broadly. This methodology should contain both the “what” of philosophy and the “how” of a technique without being prescriptive, proscriptive, or rigid. In one of the original works on design, the design process is described in seven stages: define, research, ideate, prototype, choose, implement, and learn (Simon 1968). In the more recent and highly regarded *Design of Business*, (Martin 2009) this is described as moving through the “knowledge funnel” from *mystery*, something we do not understand but want or need to, to *heuristic*, a rule of thumb applied by experts to solve the mystery, to *algorithm*, a process that can be standardized, taught, and implemented in a business model. Martin also stresses the concepts of validity (solving the right problem), and reliability (solving the problem right).

Design began to move into military thinking through a concept called systemic operational design and then into the U.S. military through the School of Advanced Military Studies (SAMS) of the Command and General Staff College (Banach and Ryan 2009). This work led to publication of student texts and articles, and incorporation of design into doctrine.

2.7.4 Army design methodology

The Army design methodology is “a methodology for applying critical and creative thinking to understand, visualize, and describe problems and approaches to solving them” (U.S. Army 2012b). It is a complement to, not a replacement for, the military decision-making process (MDMP). In its most basic formulation, the Army design methodology enables commanders and staffs to understand, visualize, and describe a current state and a desired future state in the operational environment, then to frame the problem set by understanding, visualizing, and describing the obstacles preventing progress toward the desired state, then develop operational approached to overcome these obstacles, and conduct detailed planning through the MDMP to implement the operational approaches. This process is visualized in Figure 14.

Figure 14. Army design methodology from ADRP 5-0 (U.S. Army 2012b).



Essential to the successful application of the Army design methodology is the ability of the commander and staff to understand, visualize, and describe the operational environment or simply put, the ability to look outside the wire, see what is there, understand what that means, and communicate this to the planning team.

2.8 "To the left of" understanding

In Army slang, "to the left of" means "before." CLOIS, design thinking, and the Army design methodology all begin with understanding the operational environment, but what is "left of understanding"? In other words, what preparation is necessary before we can understand? How does a commander or staff become educated and prepared to understand something as complex as infrastructure, and to then visualize and describe it in such a way that the description supports achievement of tactical, operational, and strategic ends? What thinking frameworks do commanders and staffs bring to bear on this challenge?

The Army provides a variety of thinking frameworks for leaders, all of which are taught "to the left of" the required thinking. The operational variables of PMESII-PT (political, military, economic, social, information, infrastructure, physical environment, time); the mission variables of METT-TC (mission, equipment, time, terrain, troops, civilians), the military aspects of terrain of AOKOC (avenues of approach, observation and fields of fire, key terrain, obstacles, cover and concealment), the civil considerations of ASCOPE (areas, structures, capabilities, organizations, people, and events), and the infrastructure sectors of SWEAT-MSO (sewage, water, electricity, academics, trash, medical, safety, other) are among the best known and most used.

These frameworks are necessary and useful, but not sufficient for understanding infrastructure. The infrastructure variable in PMESII-PT tells us that infrastructure is important to the operational environment. History and mission assessments tell us that civilians are often the key terrain in a counter-insurgency AOKOC, and some elements of civilian considerations can be described by ASCOPE. Finally, some of the infrastructure sectors can be listed in SWEAT-MSO, but this “E” focuses on electricity and ignores all other energy sources. As useful as these frameworks are, none provide a sufficient framework for thinking critically, creatively, and completely about infrastructure. The “S” in SWEAT can tell us sewage is important, but it cannot tell us why the sewage system is not working, where we should look for the problem, and what functions are necessary to restore the system. The same is true for the remaining “WEAT” terms and all the infrastructures not represented in this acronym.

“Left of understanding” is manifested in the realm of education and scholarship. It is education that prepares students to solve future. It is education that prepares future leaders to be critical, complex, and adaptive thinkers. The requirement to prepare future Army officers and engineers to understand, visualize, and describe infrastructure problems and lead organizations in solving them drove the development of the infrastructure models described in this report and the educational programs that teach them.

3 Educating for Infrastructure Leadership

3.1 Curriculum evolution to infrastructure

In 2008, leaders of West Point's Department of Civil and Mechanical Engineering began an extensive review of the civil engineering curriculum to ensure it was meeting the needs of both primary constituents: (a) the Army with a special focus of the Engineer Regiment and (b) the civil engineering profession at large. Fortunately the assessment revealed that both constituents needed the same thing—graduates capable of solving infrastructure challenges. We realized that, while we did know how to teach specific elements of the infrastructure, we did not know how to teach students a complete, holistic, integrated, and multi-disciplinary approach to infrastructure. After reviewing coursework at many institutions, we concluded that no one did. Based on the need and lack of viable solutions, we set about to fill the "left of understanding" void on infrastructure.

3.2 Developing conceptual models for infrastructure

We knew that we could not teach everything about every infrastructure problem, so we set about to develop and then teach frameworks to understand and solve infrastructure problems by using conceptual models as frameworks to understand, visualize, and describe both a current state of infrastructure and a desired future state. This would allow students to deal with future challenges by using the models, all accumulated knowledge, and all information on a problem at hand.

Based on the definition of infrastructure and the complexity and variety of infrastructure systems, we determined that the models must satisfy many characteristics.

- The models must be technically correct and complete.
- They must explain infrastructure systems at a variety of scales.
- All elements of the systems must be clearly identifiable and coherently captured in the model framework.
- The user must be an essential element of the models.
- System control (e.g., technical, financial, and regulatory) must be addressed.

- Perhaps most importantly, the models must be both simple and complete, making them expandable to match the expertise of the user and the complexity of the infrastructure in question. These last characteristics also serve to prevent a profusion of models, since they increase the likelihood of the adaptability of models for many systems and situations, both present and future. Simplicity also provides accessibility to all citizens, regardless of background, using commonly understood terms that do not conflict with accepted technical or professional definitions. The models thus allow people to come to a common understanding while facilitating an increased depth of understanding with increased experience.
- Lastly, to promote their use, the models must be memorable.

In the process of developing the models, it quickly became apparent that the goal of understanding, visualizing, and describing infrastructure would require a family of models, as each level of understanding prompted additional questions. Accordingly, the West Point Infrastructure Models were developed as four interrelated models with an additional description of the infrastructure environment—those elements that are not the infrastructure itself but directly impact the designing, building, operating, using, and maintaining of infrastructures.

It is important to understand what the models are and are not. They are a cognitive framework for understanding, visualizing, and describing infrastructure so that commanders, staffs, planners and citizens can think critically, creatively, and completely about infrastructure issues. They furthermore are useful for communication with and collaboration between a diverse group of stakeholders. They are not the only tool necessary to find the “final answer,” but rather they are the start point on the path to find the answer and a guide for evaluating the quality and completeness of the final answer. They are not replacements for technical design, policy statements, laws, or funding mechanism, but rather they are frameworks that help leaders, managers, and citizens integrate these expert disciplines. Bear this perspective in mind when reading about and applying the models.

A full explanation of both the curriculum and model development is reported in multiple papers including: Klosky 2012; Hart et al. 2011, and Meyer et al. 2010.

4 The West Point Infrastructure Models

4.1 Objectives of infrastructure models

The West Point Infrastructure Models are a transilient, cognitive architecture that allows commanders, leaders, planners, managers, and citizens to think critically, creatively, and completely about infrastructure problems; identify and engage with all stakeholders; and formulate and implement solutions that are technically, socially, environmentally, economically, and politically viable. From the military perspective, the models are tools to link decisions on the infrastructure variable across all phases of a campaign as was shown in Figure 1. From a civilian perspective, the models are tools for infrastructure leadership in that they provide a common language for discussions and consensus building across all phases of project delivery beginning with need, moving through funding, having a ribbon cutting, and sustaining the project through proper maintenance.

The models work in order, but application of each subsequent model will reveal new information or perspectives which will force revisiting and reconsidering the prior models. First, the Infrastructure Environment Model promotes understanding of all the factors that shape the infrastructures in question. Then, the Infrastructure Component Model allows the infrastructures to be identified and described; it supports seeing what is there and envisioning a future desired state of an infrastructure. Next, the Infrastructure Assessment Model helps to understand the quality of what is present. If quality is satisfactory, then no actions are required. More likely, however, application of the Infrastructure Assessment Model will reveal some deficiencies in the current state. At this point, the Infrastructure Development Model and the Infrastructure Resilience Model are applied to move the infrastructure from the deficient current state to the desired future state. Coming full circle, the Infrastructure Component Model can be used to visualize and describe this future state, and the Infrastructure Environment Model can be employed to support the shaping of this state.

These five models are consistent with the requirements of Army doctrine which spells out two specified tasks related to infrastructure: (1) Protect and (2) Restore/Develop. Restore and Develop are related tasks with different starting points. Restore implies an infrastructure was present, subsequently damaged, and needs to return to its original configuration, while

Develop means the infrastructure is insufficient in its current state. Prior to these tasks, the infrastructure must be seen and assessed. The Infrastructure Environment and Infrastructure Component Models enable visualization, the Infrastructure Assessment Model supports assessment, and then the Infrastructure Development and Infrastructure Resilience Models support the two doctrinal specified tasks.

4.2 Infrastructure Environment Model

Infrastructure exists inside a multidimensional space with factors that have nothing to do directly with the infrastructure itself. These factors shape the infrastructure in question by both imposing constraints and providing enabling mechanisms. These factors are always present, yet are often applied differently at different times in an infrastructure's life cycle. Failure to properly understand and account for these factors typically leads to infrastructures that are ill-suited for the space they occupy and thus fail. A proper understanding of these factors leads to suitable infrastructures which successfully achieve the desired ends.

4.2.1 Needs

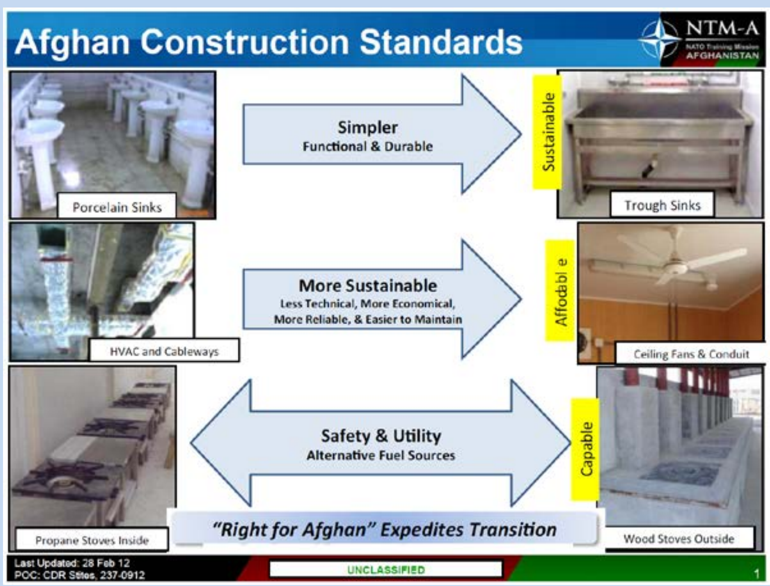
Infrastructures exist to meet a need. Identifying, quantifying, empathizing, and appreciating the need is essential to understanding the infrastructure that meets or will be created to meet the need. The need must be determined and viewed from the point of view of the user. This is especially important when working in someone else's country or neighborhood. Not everyone views an issue in the same light. Failing to properly understand and frame the needs will lead to solutions that do not meet the needs. The following summary from SIGIR 2013 neatly states that point.

The lack of agreement from the US leader perspective speaks to the Infrastructure Environment aspect of Needs. Since the US leaders had trouble coming to a consensus on the actions that needed to be taken, they inherently showed that they did not understand what the Iraqi society needed to get out of the infrastructure programs and projects (SIGIR 2013, 20-26). The failure in identifying those needs AND communicating them to all leaders involved in the infrastructure reconstruction meant the US efforts were inherently disjointed. This can be contrasted with the Iraqi leadership, who understood what it was that their citizens needed. The Iraqi leadership's ability to point to three specific actions that were lacking from the US government shows that they understood the needs of the society (SIGIR 2013, 13).

Understanding the needs means understanding when and how those needs will evolve. The following words from COL Samuel M. Ligo and Figure 15 (taken from Glenn 2012) demonstrates this point.

"The slide (reproduced as Figure 15 here) shows how we've transitioned over the years from what you would consider western standards to standards much more appropriate for the ANSF. The last pair of pictures, though, is a different concept. On the left are indoor gas stoves. On the right, outdoor wood stoves. We began putting both types in all DFACs [dining facilities]. The un-indoctrinated would consider this redundant. However, we do it on purpose. The reason is that the Afghans prefer to cook with wood, but it is a scarce resource. They do have a lot of natural gas, and eventually it will be distributed either by pipeline or bottles. It already is to a degree, but it will become more prevalent. In our earlier builds, we put in only gas stoves and we found that the Afghan cooks were actually burning wood in the gas stoves, ruining the stoves and filling the kitchen with smoke. So we began installing wood stoves outside the kitchen in a roofed shelter while still installing the gas stoves inside the kitchen. So, they're set for the long term."

Figure 15 Evolution of Afghan construction standards (Glenn 2012).



4.2.2 Social

Because infrastructures exist to meet a societal need, infrastructure problems are social problems, and the nature of society and its economy shapes the nature of the supporting infrastructure. The social factor is also one of the Joint Operating Variables, and in infrastructure analysis, one looks for particular aspects that shape infrastructure including: standard of living, literacy and education, relationship of culture and technology, employment patterns, and population density and distribution. Not only does society shape what is possible for infrastructure projects, installation of a new infrastructure project will change the society. The perception of the impact of this societal change will affect the acceptance or rejection of the infrastructure project.

The case of Haiti after the January 12, 2010 earthquake provides an interesting case study on the power of political and social dynamics to shape what is possible in infrastructure development. The following is summarized from Department of State (2011):

> Some statistics suggest that Haiti has a 90% unemployment rate, when in actuality 15% of the population is employed in the formal economy and 70% is employed in the informal economy, resulting in a true unemployment rate of 15%. One essential element for a functioning formal economy is the capacity to document, enforce, and protect individual property ownership. Without this system, it is most often the poor whose property is unprotected. Not only does lack of a land registry complicate post-disaster response and recovery (e.g., who owns that vacant land where we want to put the internally displaced persons camp anyway?), it also discourages citizens from wanting a building code and supporting its enforcement. Without a guaranteed title to the land and improvements on the land, why would anyone want to build to a higher, more expensive standard? While Haiti does possess a building code and enforcement system, its enforcement is lax and often opposed by builders and building owners. The chief engineer for the city of Leogane reported that, “City Hall doesn’t issue more than ten permits a month,” and inspectors are often driven from job sites by angry contractors and crowds. These conditions are so detrimental to effective rebuilding that the *Post-Earthquake USG [United States Government] Haiti Strategy* (Department of State 2011) report calls for the establishment of a system of formal land ownership and registration and enforced building codes before effective long-term reconstruction can begin. Effective infrastructure reconstruction must be preceded by social and political change and may be pointless without it.

4.2.3 Political

The body politic is a mechanism for implementing collective decisions, and as infrastructures typically affect large portions of society, infrastructure actions typically have a significant political component. Like the social factor, this is also a Joint Operating Variable which, in infrastructure analysis, focuses on political structures that shape infrastructure include: property ownership, regulation, taxation, rule of law, and building codes and their enforcement.

4.2.4 Technical

Infrastructures use technical means to meet societal needs; thus the technology employed must be appropriate to the society. The society in question must be able to understand, design, build, operate, and maintain the infrastructure technology employed. Additionally the technology must be appropriate to the physical environment of the society. In striving to match appropriate technology with need, planners must ask, “Do we adapt the project to use local technology, or build capacity to use a new technology?” The former causes a problem for U.S.-based designers unfamiliar with local materials for which a design code may not exist and the latter may cause societal turbulence in the assisted nation, construction delays, and substandard work.

An example of the absence of culturally correct, indigenous construction materials and techniques is given by LTC Legena Malan in the following highlighted text and Figures 16 and 17 (Malan 2012).

LTC Legena Malan of the United States Navy Civil Engineering Corps reported her experiences with mismatches in the designed and locally adapted technologies in Nuristan (Malan 2012). The design called for steel-based structures, a nonlocal material that had to be transported over treacherous roads and with which local contractors were not familiar (Figure 16). The result was a low-quality product, project delays, and frustrated contractors.

Figure 16 Original design requirements using foreign techniques (Malan 2012)

When the designs were changed to use local materials and construction techniques (Figure 17), contract quality, contractor performance, structural stability, and U.S.-Afghan relationships all improved.

Figure 17 Construction using locally adapted techniques (Malan 2012).

4.2.5 Financial

Infrastructure costs money, and someone has to pay. The capacity of the involved parties to pay for the design, construction, operations, maintenance, and decommissioning of the infrastructure shapes what is possible. Then, the capacity of the users to pay for the service—in terms of having the money, being able to receive the bill, and having a mechanism to pay the bill—shapes the long-term viability of the infrastructure.

In development situations, funds are often readily available from donor nations to start a project with sustainment of that project falling to the host nation. In Afghanistan, consistent with both US law and policy, DoD, DoS, and USAID require that an Afghan government agency receiving an infrastructure project sign a letter indicating their willingness to operate and sustain the project and demonstrate their capacity to do so. In spite of this requirement, the Special Inspector General for Afghanistan Reconstruction (SIGAR) reports, "Because implementing agencies did not develop adequate sustainment plans, and project sustainment relies on Afghan entities with questionable capacity and on unidentified and unfunded projects or projects with completion dates beyond 2014, Congress and the U.S. taxpayers do not have reasonable assurance that projects implemented using fiscal year 2011 AIF funds will be viable or sustained by the Afghan government after completion." Additionally, the SIGAR recommended that each project include a sustainment plan consisting of sustainment cost estimate, funding source, acknowledgement of sustainment responsibility by the host nation, and an assessment of the host nation to carry out the sustainment (SIGAR 2012)

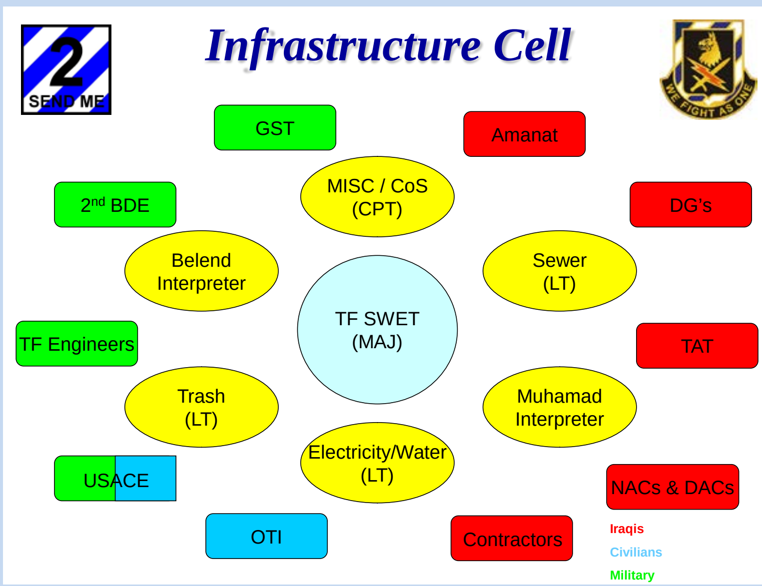
4.2.6 Organizational

Infrastructures are complex networks and cannot be designed, built, or operated by isolated individuals. Organization must be viewed from the perspectives of both the assisting nation and the assisted nation. The assisting nation must establish organizations for stakeholder engagement, design, construction, capacity development, and transfer. These organizations are often not standing organizations, and they must be stood up, manned, and equipped on an ad hoc basis. The capacity of the assisted nation to establish the organizations to design, build, operate, maintain, and regulate the infrastructure further defines what infrastructures can be effectively implemented in the society and thus provided by the assisting nation. (SIGAR 2013, 25, 57).

Organization applies at both the national level (as evidenced by the creation of the USACE Gulf Region Division with three supporting districts) and at the unit level, as explained below.

COL S. Jamie Gayton, commander of 2-3 Brigade Special Troops Battalion (BSTB) of the 2nd Brigade, 3rd Infantry Division, deployed to Sadr City for Operation Iraqi Freedom (OIF) III from JAN 05 to JAN 06. His battalion was not a battle space owner within Sadr City, but it was instead responsible for supporting the Reconstruction, Governance, Economics, and Information Operations logical lines of operations by coordinating and managing all reconstruction efforts in the brigade's area of operations. The BSTB was never designed for this task which caused COL Gayton to reorganize portions of his unit into an infrastructure cell or TF (Task Force) SWET (Sewer, Water, Electricity, Trash) as shown in Figure 18 (from Gayton 2012).

Figure 18. Graphic of reorganization of infrastructure cell units (Gayton 2012).

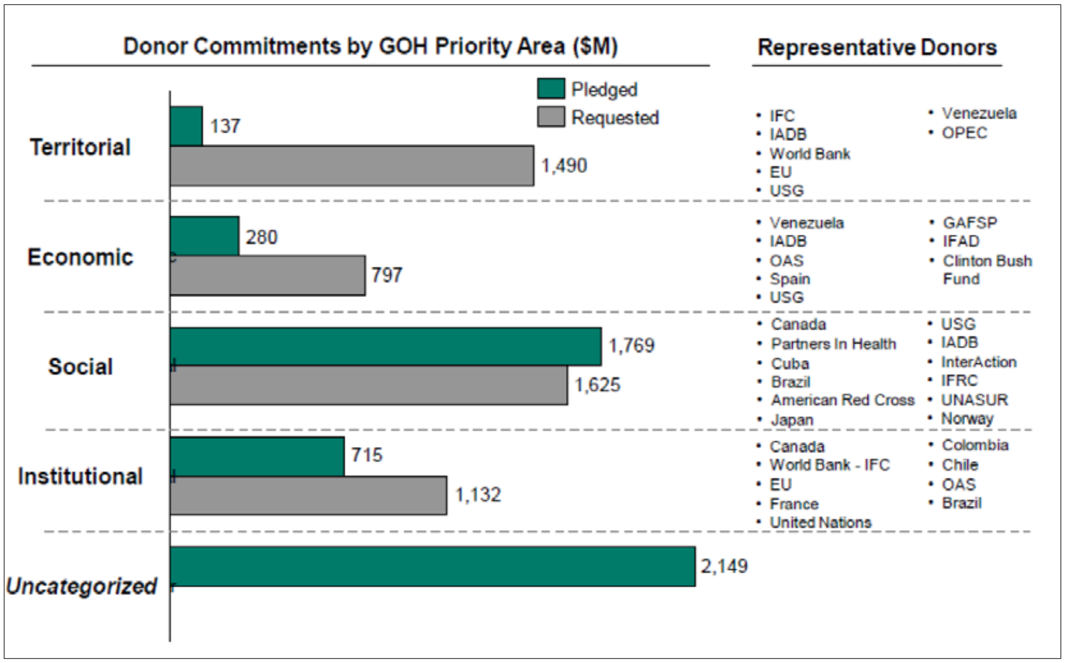


> The SIGAR Report (2013) states that U.S. efforts were marked by obligating large amounts of funds early in the reconstruction process. The Iraqi government was not functional (according to U.S. military leaders) to oversee reconstruction until 4–6 years after the majority of funds were obligated. This discrepancy in time highlights the fact that the primary stakeholders from the Iraqi government could not be partnered with—those Iraqi leaders were not even in office at the time that the majority of funds were being allocated.

4.2.7 External

Every society and every infrastructure exists inside a wider framework with factors that shape the infrastructure. Externalities are different in every case, but they include factors like donor nations contributing to disaster relief in a developing country, national requirements that affect state and local decisions in a federal system of government, and international standards designed to ensure interoperability. For example, Figure 19 shows donor commitments of funds in support of the Government of Haiti's rebuilding priorities (Department of State 2011). When understanding the infrastructure environment, planners must understand the intent and capability of external actors and develop plans to work with them instead of at cross purposes. Supported countries must also understand that money always comes with strings or put another way, "He who has the gold makes the rules."

Figure 19. Post-earthquake pledges and commitments to the Government of Haiti (Department of State 2011).



4.2.8 Enemy

Infrastructure is one variable in the operational environment. Friendly forces, allied forces, host nation forces, neutral forces, civilians, and the *enemy* all live and operate inside that operational environment. Thus any change in the operational environment, such as building an infrastructure project, will affect all players in the environment to different degrees. Therefore, every infrastructure project must be evaluated from the enemy's perspective: Who benefits from the project and how? How with this project increase enemy mobility? Will this provide the enemy with additional targeting opportunity? How will the enemy use this in their information operations? Mark Moyar (2011) accurately assessed how infrastructure projects could inadvertently strengthen the enemy's position, as shown in the highlighted excerpt below.

> "The impact of a project is routinely considered in terms of how well it addresses U.S. objectives and/or assists the local population. The potential impact on the threat is rarely taken into account. In other insecure areas, the insurgents allow development to proceed in order to leech off of it. Numerous development contractors in Afghanistan pay protection money to private security companies or local power brokers because the counterinsurgents lack sufficient forces in the area, and oftentimes this money falls into Taliban hands through intimidation or collusion. Military superiority also allows the insurgents to reap the economic benefits of completed projects. For instance, the United States spent more than $100 million repairing and upgrading the Kajaki hydropower plant to provide electricity to Helmand and Kandahar provinces, but last year half of its electricity went into areas where the insurgents control the electric grid, enabling the Taliban to issue electric bills to consumers and send out collection agents with medieval instruments of torture to ensure prompt payment. The consumers in these places use the power for the irrigation of fields that grow poppies, which in turn fuel the opium trade from which the Taliban derive much of their funding."

4.2.9 Summary

Before proceeding with any infrastructure action, leaders and planners must understand and appreciate the impact of these eight factors. Failure to do so will result in an infrastructure that does not perform as desired or makes the situation worse. Once the infrastructure environment is understood, the infrastructure inside that environment can be seen.

4.3 Infrastructure Component Model

Infrastructures are networked systems—sometimes simple, but often complex—that exist to provide a service to society; the Infrastructure Component Model describes the key elements of such systems by using six elements: generation, bulk transmission, distribution, use, waste management, and coordination. These six elements can be recalled by using the mnemonic "<u>G</u>rizzly <u>B</u>ears <u>D</u>on't <u>U</u>se <u>W</u>ater <u>C</u>losets" (GBDUWC). Figure 20 is an illustration intended to further reinforce the model's key elements for those learning or recalling the model. The Infrastructure Component Model provides a basis for identifying, visualizing, and understanding the elements of an infrastructure, the functions they perform, and their relationships to each other. The six elements are both necessary and sufficient for the proper function of an infrastructure system. Though these six elements are listed as nouns, they should be viewed as verbs because these are the six functions of an infrastructure. Focusing on the functions enables better understanding because one infrastructure may perform multiple functions or multiple infrastructures may be necessary to perform one function.

Figure 20. Grizzly bears don't use water closets, an illustration of the mnemonic to recall the six elements of the Infrastructure Component Model (illustration by Major Cullen Jones, U.S. Army 2012).

4.3.1 Generation

Generation encompasses all processes necessary to create a final product in bulk. This might include extracting a raw material, converting it to a usable form, and preparing it for bulk transmission.

4.3.2 Bulk transmission

Bulk transmission moves large quantities over long distances. Bulk transmission systems typically have limited connection points, and may include reprocessing systems to facilitate distribution.

4.3.3 Distribution

Distribution moves smaller quantities shorter distances culminating at to a user. Distribution may include conversion into a consumable form.

4.3.4 Use

Use is the consumption of the product or service by a paying customer. The user is an essential and highly complex element, and might be an individual or another system.

4.3.5 Waste management

Waste management encompasses all activities associated with waste. This may include actions such as ignore, dispose, recycle, reuse, or repurpose, as well as waste elements from solid to gaseous to thermal. It is the experience of the authors that this element is often widely mis-assessed in terms of societal importance in conflict zones.

4.3.6 Coordination

Coordination ensures the smooth functioning of the infrastructure system and includes functions like SCADA (Supervisory Control and Data Acquisition) systems, the financial mechanisms for billing customers, maintenance, and regulation. An example from the SIGIR report is highlighted:

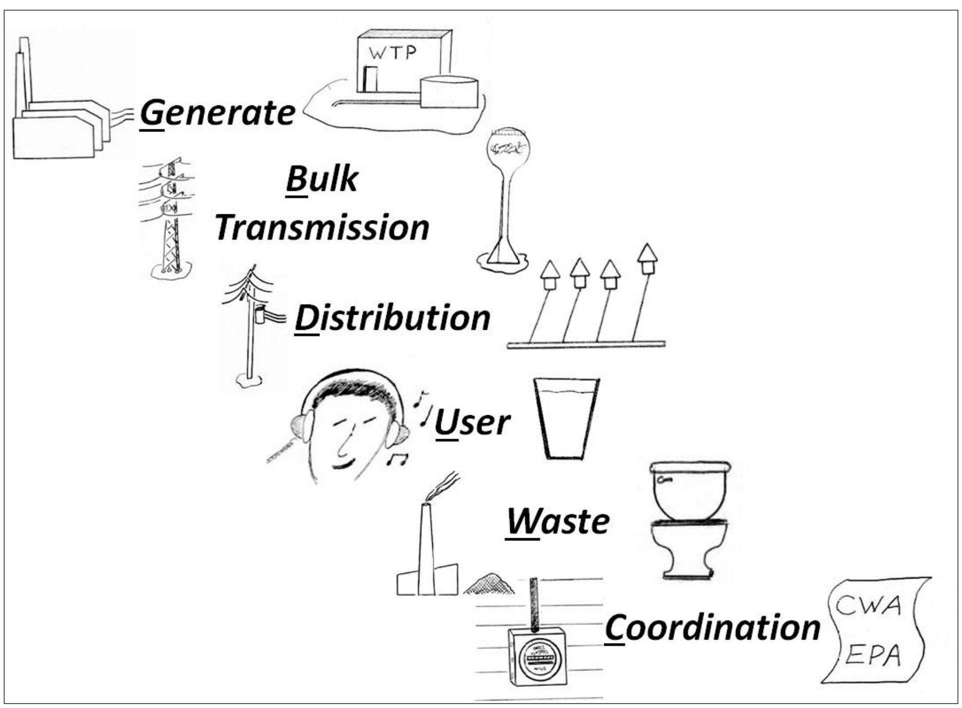
> For an electrical grid to be effective, it must generate the same amount of power that the users are demanding, in real time. The inability to store electricity efficiently means that the whole system must be highly coordinated around the user's demands. The US focused on "generation, transmission and distribution projects.". The US did not focus on ensuring the entire system was coordinated. Throughout reconstruction as power generation increased, the demand increased even more rapidly. This meant that the electrical generation never became balanced with the demand. This lack of coordination led to 80% of respondents to a survey on electrical quality to rate the service as either "bad" or "very bad." (SIGIR 2013, 76, 79)

4.3.7 Discussion

While it can be applied to any infrastructure system, the Component (Grizzly Bear) Model tends to work best with what might be termed *civil infrastructures*—infrastructure systems with a physical backbone or with predominately physical elements. A sample application of the model to two infrastructures is shown in Figure 21. These sample applications are meant to be strictly illustrative; this model has been applied by the authors and others to a wide variety of infrastructure systems and has proven very robust in setting coherent frameworks for describing such systems.

The model also captures the interdependencies between infrastructures. A water treatment plant is a *generator* in the water system but a *user* in the electrical system model, while a coal-fired power plant is a *generator* in the electrical system but a *user* in the water system. Further, the Infrastructure Component Model is scalable in that it can accurately describe infrastructures of different sizes. Figure 21 shows the model applied to regional systems; however, a household water system can be equally well represented by thinking of a well with a pump as *Generation*; service entrance pipe as *Bulk Transmission*; smaller pipes running throughout the house as *Distribution*; sinks, toilets, tubs, and washing machines as *Users*; the septic system for *Waste Management*; and the pressure switch controlling the pump (while the parents sternly tell the children to turn off the shower) as *Coordination*. Lastly, the Conceptual Model allows planners to understand and visualize an infrastructure system, but it does not speak to the quality of that infrastructure and the service it provides; the desire to express quality led to the development of the Infrastructure Assessment Model.

Figure 21. GBDUWC applied to electrical and water systems (illustration by Led Klosky).



4.4 Infrastructure Assessment Model

The Infrastructure Assessment Model allows users with varying levels of expertise to rapidly assess and describe the status of infrastructure components and systems. While the model is certainly robust enough for long-term assessment of well-understood systems, it also is well suited for use in post-disaster and conflict zones, where not all the involved agencies and personnel will have a strong background in infrastructure or engineering. Thus, the model must be comprehensive, yet not overly prescriptive or complex, and it must be applicable to a variety of infrastructures, providing a robust framework that guides a user towards formulating appropriate assessment metrics.

The Infrastructure Assessment Model consists of six prompts which guide the formulation of focused assessment questions that consider the performance of systems and components, identified in the Conceptual Model, under both normal and adverse circumstances. The six prompts are *Required*, *Ready*, *Organized*, *Tough*, *Redundant*, and *Prepared*. The first three prompts, *Required*, *Ready*, and *Organized*, focus principally on infrastructure operation under normal conditions. In each of the explanations below, sample questions are presented; these questions are by no means comprehensive, but instead are intended to illustrate some possible questions that the prompts might inspire.

4.4.1 *Required* prompt

The first prompt, *Required*, focuses primarily on the *User* element of the Infrastructure Component Model. By beginning with user demand, this focus aligns well with current thinking on disaster recovery, development work, and nation building. This prompt identifies the user's needs and leads to the formulation of questions like those listed below.

- What is the peak daily demand for power?
- What is the water quality needed for this use?
- How are people able to receive/store/employ the resource?
- How does demand vary over time and distance?
- Is the demand consistent?

The *Required* prompt often leads to quantitative answers as well as lays a firm foundation for what will be required of the *Generation*, *Bulk Transmission*, and *Distribution* components. Further, modelers must consider the individual user's perspective as well as requirements aggregated in neighborhoods, communities, and regions.

4.4.2 *Ready* prompt

The second prompt, *Ready*, focuses on the *Generation, Bulk Transmission*, and *Distribution* elements of the Infrastructure Component Model by asking what these elements are capable of delivering at the current time in their current configuration. The *Ready* prompt leads to the formation of capacity-focused questions like those listed below.

- What is the capacity of the existing roadway system?
- How much fuel can be refined?
- Is there a seasonal variation in the quality or quantity of water available?
- Are the required supplies, material, and manpower reliably present?

Like the *Required* prompt, the *Ready* prompt generates questions that tend to be quantitative in nature. This allows for a user-focused comparison of supply and demand, providing valuable information on system performance now and on what capacity is available to support future development.

4.4.3 *Organized* prompt

The third Infrastructure Assessment Model prompt, *Organized*, principally assesses the *Coordination* element of the Conceptual Model, leading to assessment questions that are both quantitative and qualitative. Assessment questions focus on all aspects of *Coordination*:

- What are the financial mechanisms for the infrastructure and are they working?
- Are sufficient and trained maintenance personnel available?
- Is the system managed in a legal, just manner, or is it corrupt?
- Do SCADA systems maintain operation within acceptable parameters?
- Do regulations provide appropriate environmental protections?
- What is the mean time of repair for system breakdowns?

In sum, the *Organized* prompt seeks to determine whether the infrastructure is meeting the needs of the society it serves, is financially viable, is functioning correctly from a technical perspective, and is sustainable from social, environmental, and business perspectives.

The *Required*, *Ready*, and *Organized* prompts must also be applied to the *Waste Management* element of the Infrastructure Component Model. Assessment questions could include those listed below.

- How much waste by type is generated?
- How are different waste streams being managed and by whom?
- What is the functional life of the management method (e.g., landfill, incinerator)?
- What percentages of waste streams are or could be recycled, reused, or repurposed?
- How much of the waste is simply ignored and deposited into the environment?
- Are appropriate governmental regulatory frameworks in place and enforced?

As in the earlier discussion of *Waste Management* in Section 4.3.5, it is the personal observation of this report's authors that this element is often either ignored in planning or an afterthought, resulting in long-term negative impacts on society and the environment that marginalize the intended positive outcome.

The first three prompts of the Infrastructure Assessment Model are an essential starting point; the next three prompts, *Tough*, *Redundant*, and *Prepared*, generate questions that assess an infrastructure's performance under adverse conditions and share elements with the Resilience Framework proposed by the Multidisciplinary Center for Earthquake Engineering Research (MCEER 2006).

4.4.4 *Tough* prompt

Tough is focused on *Generation* and *Bulk Transmission*, although key elements of the *Distribution* systems may need to be tough as well. These infrastructure elements tend to be expensive, hard to replace, and their loss leads to broad delivery disruption. As such, they must be able to survive or quickly recover from adverse conditions, returning to service very rapidly. To assess toughness, one might ask questions like those listed below.

- Is the element in a flood plain?
- Would the element survive the most likely disruptive event(s)?
- Is the element secure against infiltration and attack?
- Is it mechanically reliable or prone to frequent breakdowns?
- Does it have a history of success or failure in previous hazard events?
- Are there personnel, supplies, and procedures in place to affect recovery operations?

An element that is *tough* can absorb or very rapidly recover from the effects of a hazard event, performing its required function in the immediate aftermath of a disruption.

4.4.5 *Redundant* prompt

The *Redundant* prompt maps well to the *Bulk Transmission* and *Distribution* elements of the Infrastructure Component Model, although additional *Generation* capacity may also be desirable. Transmission and distribution systems are typically spread out over great distances and, while these systems are designed to withstand normal circumstances, their size makes it cost prohibitive to harden them against extreme events. Therefore, they either must possess sufficient redundancy to continue functioning with the loss of some elements or be rapidly repairable. Assessment questions derived from the *Redundant* prompt include those listed below.

- Do multiple paths for *Bulk Transmission* and *Distribution* exist?
- Is my *Generation* system single-point?
- Is local emergency storage or generation available?
- Are there transmission and distribution system hubs that would cause widespread failure if damaged?
- What was the rate of service loss and restoration in the last three disasters?
- Are enough repair crews trained, equipped, and available?

The *Redundant* prompt focuses on determining whether the system can withstand the loss of some elements and whether it can be rapidly restored in the event a substantial number of elements are lost or damaged.

4.4.6 *Prepared* prompt

The final Infrastructure Assessment Model prompt is *Prepared*. It applies across an entire infrastructure system, focusing especially on the *User* to determine if the *User* is prepared to survive the inevitable disruption in the service provided by the infrastructure. Assessment questions would be like those listed below.

- Are users aware of the frequency and duration of potential service disruptions?
- Are there plans, assets, and properly trained personnel available to deal with disruptions and to restore service in an orderly fashion?
- Is the user able to survive disruptions by using other means?
- How does the community deal with citizens and organizations that did not prepare?
- Do the plans and assets consider and address highly vulnerable populations?

Infrastructures serve a societal need. When the infrastructure fails, that need does not disappear. Users who are not prepared for adverse events make significant demands on governmental and societal systems that are also in distress, thus compounding problems for all. *Preparation*, when supported by *Toughness* and *Redundancy*, can reduce the overall impact of an adverse event and speed the restoration to normalcy.

4.4.7 Discussion

As formulated above, the six prompts of the Infrastructure Assessment Model guide the formulation of an assessment scheme for an infrastructure system. The same prompts can be used for the assessment of a specific item in an infrastructure, although the degree to which each prompt applies will vary with the item assessed.

For example, if applied to a water tower, applying the Infrastructure Assessment Model might take the following form.

- *Required*: What is the required storage capacity based on all the uses?
- *Ready*: What is the capacity of the tower in terms of volume stored and input/output rates?
- *Organized*: How is the level in the tower controlled, and by whom?
- *Tough*: Is the tower designed to survive appropriate disruptive events?
- *Redundant*: Is the tower supplied by a single bulk transmission pipe or by multiple?
- *Prepared*: Is there a backup generator with fuel, or manual methods of filling and controlling available?

Infrastructures exist to serve society. Properly applied, a well-formed Infrastructure Assessment Model of a particular system can provide valuable information for infrastructure planning, building, operation, upgrade, and restoration. Using the six prompts of the Infrastructure Assessment Model to guide the formulation of questions, the modeler can qualitatively and, in some cases, quantitatively describe that service under both normal and adverse conditions—a valuable tool for planners, operators, and responders. It must be remembered, however, that assessment is more circular than linear and that as one prompt is addressed, others must be revisited based on each new piece of information gained.

4.5 Infrastructure Development Model

Infrastructure development falls under the Army's second core competency, Wide Area Security, and is manifested to two of the five stability tasks: "Restore Essential Services" and "Support to Economic and Infrastructure Development". Our doctrine goes on to state (U.S. Army 2012a):

> As part of unified land operations, Army forces may assist the development of host-nation security forces, a viable market economy, the rule of law, and an effective government by establishing and maintaining security in an area of operations. The goal is a stable civil situation sustainable by host-nation assets without Army forces. Security, the health of the local economy, and the capability of self-government are related. Without security, the local economy falters, populations feel unsecure, and enemy forces gain an advantage. A functioning economy provides employment and reduces the dependence of the population on the military for necessities. Security and economic stability precede an effective and stable government.

None of the objectives described in this excerpted paragraph are possible without a developed infrastructure. Doctrine, however, does not offer a definition of infrastructure development, so the following definition is proposed.*

Infrastructure Development is the organized effort to restore or improve critical infrastructure in an unstable nation or society through the coop-

* This definition was developed by Cadets Brendan Buckley, Amanda Darling, Heather Hernandez, Christer Horstman, Luke Loftsgaarden, Joseph Lorfink, Marc Pesa, Daniel Prior, and Brennan Randel and LTC Steven Hart for the class CE490A, "Formulating an Infrastructure Development Model" in the Fall of 2012.

eration of local, national, and international groups for the purpose of achieving political, economic, and social stability and building a foundation for future growth.

This proposed definition attempts to capture WHAT the Army must do, WHO the Army interacts with, WHY the Army is interested, and the limits of Army responsibility. Infrastructure forms the basis for stable civil society and government, and the Army needs this stable local society and government to assume responsibility for an area so that the Army can leave, which is WHY the Army is interested. To achieve this stability, the Army must do two things (WHAT): (1) *restore life-sustaining infrastructure* to meet essential needs and (2) *establish the enabling fundamentals* that allow other agencies including international, governmental and nongovernmental ones (WHO), to move into an area and begin working. A necessary condition for both of these is the establishment of a secure environment. The concept of enabling fundamentals serves as the limit for the Army's responsibilities. The Army cannot be responsible for fixing everything, and our nation lacks the treasure to pay for it. Instead, we should focus on setting the environment that allows others, including the supported nation, to continue and complete the development.

The Infrastructure Development Model differs from the other models in that it cannot be scalable, because development encompasses both programs and projects which require related, but different, ways of thinking. A program is a collection or some mixture of related projects, services, routine administrative and recurring operational processes which are managed in a coordinated way to obtain benefits and control not available from managing them individually. Programs may be categorized by funding source, customer, similarity of scope, or other common criteria for which resources are allocated and collectively managed (USACE 2009).

A project is a "temporary endeavor undertaken to create a unique product, service, or result. A project includes specific activities with a defined cost, scope, and completion schedule" (USACE 2009). By way of analogy, projects are to programs as tactics are to the operational art. Because infrastructures are by nature complex, interdependent systems that are addressing infrastructure challenges require programs to integrate projects in time, space, and purpose to achieve operational and strategic ends. Accordingly the Infrastructure Development Model shown in Table 2 contains both a *Program Model* and *Project Model*. These models describe the essential elements for infrastructure development. When an element is missing or not properly considered, the desired development will most likely go awry.

Table 2. Two models within the Infrastructure Development Model.

Program Model	Project Model
Restore life-sustaining infrastructure ➢ Water and food (sustenance/victuals) ➢ Energy ➢ Shelter ➢ Air *Build enabling fundamentals* ➢ Infrastructure services ➢ Financial services ➢ Education and training ➢ Rule of law and security ➢ Regulation ➢ Public and private sectors	➢ Shortfall in need ➢ Stakeholder engagement ➢ COA development ➢ Design ➢ Finance ➢ Build ➢ Transfer ➢ Operate ➢ Maintain

4.5.1 Program model within the Infrastructure Development Model

Because infrastructures deliver services needed by society, infrastructure development programs focus on delivery of service. Because the Army often operates in areas where both infrastructure and society have been damaged by disaster or conflict, Army infrastructure development programs focus on two critical areas: (1) restoring life sustaining infrastructure and (2) building enabling fundamentals. The degree to which each area is to be accomplished is a function of the assigned mission. The first task is essential for the preservation of life in an area and the second establishes a basis for follow on organizations to build upon. The sooner appropriate international, non-governmental, and local national organizations and companies can begin infrastructure and societal development, the sooner the Army can depart.

In **restoring life-sustaining infrastructures**, the Program Model focuses on four areas: water, energy, shelter, and air—initially for preserving life and then, transitioning to further development. Without access to clean *water*, illness and death soon result, so a program must first deliver essential amounts of water to sustain life. Next follows *energy* which the people initially require for cooking, and, depending on the region, heating. *Shelter* is essential for protection from the elements, security, and culturally specific privacy concerns. At first glance, one may question the inclusion of *air*, as it is simply everywhere. Consider, however, that many recent incidents including poison gas attacks and the Fukishima nuclear disaster in Japan have resulted in airborne contamination. Furthermore, well-intentioned but poorly understood actions like the burning of trash in open pits can contaminate the air. The development program first focuses on these four areas to alleviate the immediate concerns from the disaster or conflict, and then it transitions to meeting these needs in a permanent manner for the long term.

While the Army employs infrastructure development as a tool for stability, it is neither the desire nor the goal of the Army to be in the long-term development business. The Army's strategic goal is to stabilize the situation and transition to a strong and stable civil authority. Therefore the Army development programs should focus on **building enabling fundamentals** that allow international, nongovernmental, and local national organizations and companies to begin infrastructure and societal development. While each follow-on organization will require different enablers to be developed to a different level, a good starting point is provided by the U.S. Agency for International Development (USAID) in their Local Economic Development (LED) Tool Kit (USAID 2006). Before beginning an LED program, USAID evaluates seven fundamental areas for minimum functionality; without addressing these fundamentals, an economic development program is likely to fail. It follows that if the Army is able to address these same fundamentals, then USAID and other organizations can assume the development responsibility. These fundamentals are explained briefly below; a more detailed explanation is available in the LED Tool Kit (USAID 2006). While this report focuses on infrastructure, the other dimensions must be considered because they are all interdependent and necessary.

Infrastructure services

Essential services for the population include water, wastewater, trash, and energy infrastructures. Business and government further rely on transportation and telecommunications. Without infrastructures to deliver these services individuals, families, businesses, and governments are forced to inefficiently allocate scarce resources to meeting essential needs rather than to growth and development.

Financial services

Infrastructure projects and economic development require access to financial services. Regardless of the source of funding, financial services are necessary for secure transactions. Electronic transactions can reduce corruption and theft, but only if businesses have confidence in these systems. Access to working and growth capital provided by financial systems is also essential to economic growth.

Education and training

Recall the social dimension of the infrastructure environment. The social dimension, which includes the level of education, shapes what is possible in infrastructure development. Advancing education and training can be essential to infrastructure development and may often precede it, as shown in the highlighted text below.

An example of host nation workforce development can be found with US Army Engineers in Vietnam, where local labor lacked the skills to assist with construction. Engineers addressed this issue by establishing training schools and on-the-job training programs to develop capacity in the local labor force. Additionally, the 159th Engineer Group established a training school for heavy equipment operators and was graduating a class every two weeks in 1966 (Glenn 2012).

Rule of law and security

For development to occur, people and businesses must feel secure in their persons and property. No one will invest time and treasure in a project that can be taken by force of banditry or by force of capricious law and government. Corruption, crime, and an ineffective judiciary are all conditions that must be overcome before development (including infrastructure development) can take place.

Regulations

Regulations and regulatory processes can either promote or inhibit development. The issues associated with lack of a clear land ownership registry and unenforced building codes were discussed previously as an example of the lack of regulation inhibiting development. It is equally true that excessive over-burdensome regulations can stifle development. What is desired is effective regulation, efficiently and fairly administrated, that enforces standards, promotes opportunity, incentivizes participation in the formal economy, and ensures prompt payment of bills and taxes.

Public and private sectors

These sectors are inextricably linked, with each having a specific function. One will not function well without the other. An effective public sector is essential for establishing the rule of law, appropriate regulation, and public services like police, emergency services, and utilities. The public sector exists symbiotically with a private sector that generates employment, pays taxes, and has professional and civic organizations that promote growth and development. Public-private sector relationships can develop under many models, and we must be careful not to impose an American solution in an area where it would not be culturally or socially appropriate.

4.5.2 Project Model within the Infrastructure Development Model

The Project Model is simply a common project development or problem-solving model adapted for the specific conditions and needs of the Army when operating in a deployed environment. The project model's steps were shown in Table 2 and are explained below. Application of these steps builds on the understanding developed from the Infrastructure Environment Model and bears in mind the purpose of the program that the individual project supports.

Shortfall in need

The specific shortfall in need that the project will remedy is established from the perspective of the support nation and society. This shortfall is first determined in terms of quality and quantity of the service to be provided by the infrastructure element, both now and in the predictable future; it is shaped by what is desired but constrained by what is politically, socially, technologically, and financially possible. It is imperative that Army planners approach the shortfall in need from the perspective of the supported society and not from the "We have one of these back in the U.S. and think it would be great if you had one too" perspective. Perhaps the worst thing would be to solve a problem where there is no shortfall in need or where needs are not assessed from the local perspective. Consider the case highlighted here, as related by Colonel (British Army) Alex Alderson (Glenn 2012):

> "A rational decision to us may not be a rational decision to those we are trying to bring the support to. I had a friend who inherited a situation in Kunar Province where a building that was to be a school between two villages was being used by farmers to keep their goats. It had been a difficult project because of its remote location, getting stores in, and very likely led to loss of life. Why was it being used as a goat shed? Because it had been located without thought of what the people in the two villages thought. It was put midway between the two villages [that did not get along]. Each thought sending children there would contaminate them."

Projects that fail to consider the need from the supported society's perspective tend to damage the reputation and legitimacy the local government and result in monuments to American arrogance and stupidity rather than building strong relationships and advancing stability objectives. A proper perspective on the shortfall in need is advanced by proper stakeholder engagement.

Stakeholder engagement

Stakeholder engagement is a key element in establishing the shortfall in need as well as establishing specific characteristics essential to the success of the project. In other words, Army personnel should think in terms of "they live there, they know and own the needs, they will operate the project after we leave, they will suffer the consequences if it goes wrong, and they understand the local building materials and social, political, and economic conditions." Engaging stakeholders as partners offers the possibility of success; neglecting or outright ignoring them as partners courts failure at best and creates active enemies at worst. MG Kendall Cox advances this position when he stated, "We won't get it right all the time, but at least we can get it right more often by asking a lot of people. Ask the sheik, but trust and verify after getting his input" (Glenn 2012). Recall that the Army's purpose in infrastructure development is to increase social, political, and economic stability. This purpose is more likely to be achieved where stakeholders are engaged in decision making, construction, and ownership of the project. Consider the case outlined below, from Gayton (2012):

> COL Jamie Gayton, commander of 2nd Brigade, 3rd Infantry Division's Brigade Special Troops Battalion was responsible for reconstruction operations in Sadr City during OIF III (January 05 to January 06). COL Gayton used local organizations to establish the infrastructure development needs. During each round of project planning he said, "I would only accept a priority list signed by the District Advisory Council (DAC) Chairman." This had the effect of empowering local leaders, ensuring community buy-in to projects, and avoiding appearances of favoritism. The system was so successful that one nongovernment official (NGO) came into Sadr City wanting to do a project and the DAC Chairmen told the NGO, "You'll have to go see COL Gayton to get that in the program."

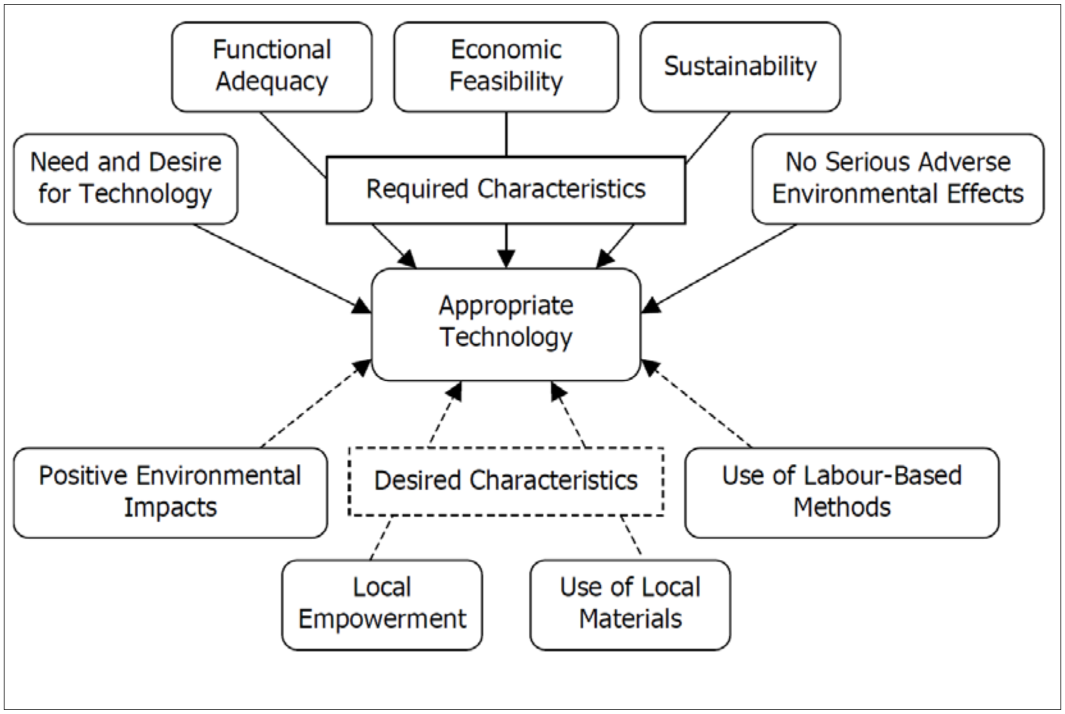
Course of action development

Once needs are assessed from a local perspective and all stakeholders are on board with the project, planners must develop and compare alternative solutions to meet those needs. Development of alternative solutions is a common task for both engineers and Army planners. Alternatives must be feasible (we can do it), suitable (actions will meet the need), acceptable (we are willing to live with the costs), complete (i.e., everything required to complete the project is included), and distinct (i.e., different courses of action must actually be different) (U.S. Army 2011b). A complete course of action (COA) for an infrastructure must take into consideration all elements of the Infrastructure Space described above. Once alternative courses of action are developed, leaders and planners compare them and select the most appropriate one. Developing appropriate metrics for evaluation is perhaps more critical than developing feasible, suitable, acceptable, complete, and distinct courses of actions. As stated by MG David Perkins, "I tell people that you have to be very careful regarding the metrics you use because what you measure drives what people do" (Glenn 2012). Metrics should assist in determining which course of action will best support the desired operational and strategic outcomes, best integrate with other projects in the program, best consideration of the elements of the Infrastructure Environment Model, and has the best chance of being successfully completed in the difficult conditions of deployment. Effective metrics for these factors are difficult to write and often difficult to assess. As a result, past planners have often selected metrics based on ease of measurement rather than predictive utility. Poorly developed metrics lead to selection of inappropriate projects which do not support strategic objectives, as illustrated by an interview on 9 NOV 2011 by Russell Glenn with GEN Peter Chiarelli and reproduced below (Glenn 2012, 131):

> "The amount of money spent was an early metric in Iraq and Afghanistan, an alleged measure of progress toward achieving counterinsurgency goals for virtually every coalition initiative in those two countries. It is perhaps the premier example of what a metric should not be. Dollars spent measured output, not effect. The metric motivated counterproductive behavior: the little controlled and poorly managed wasting of resources that inspired inflation, corruption, and poor decisions. General Chiarelli found commanders 'had to spend huge chunks of money…so [money went to] very large engineering projects…. We were literally building sewage treatment plants [when] there was no infrastructure to move the sewage to the sewage treatment plant.' Perhaps the metric was chosen less for its ability to measure progress than because it was uniformly applicable regardless of environment or reason for expenditure: it was easy to measure, easy to collate, and easy to transmit to higher echelons where it was easily understood. Presumably it was thought to be a proxy for popular support, the extent to which those receiving the money would favor coalition forces rather than insurgent and terrorist organizations. In reality it did nothing of the kind, thereby failing to achieve the essential metric characteristic of relevancy."

COA development ends in a decision which, hopefully, balances all the competing and complementary factors described here. The challenge of "appropriate technology" is not unique to the Army in stability operations. In his dissertation at MIT in 2009, Todd Radford adopted Andrew Conteh's concept that, "The essence of appropriate technology is that the usefulness or value of a technology must be consolidated by the social, cultural, economic, and political milieu in which it is to be used"(Radford 2009, 31). Based on that definition and additional research, Radford created a working assessment framework for appropriate technology infrastructure shown in Figure 22. Radford's work confirms the need to consider more than the technical dimensions alone.

Figure 22. Characteristics of appropriate technology (Radford 2009, 37).



Design

Once a course of action is selected, a detailed design must be prepared so it can be built. Engineers and planners know how to design, but in a contingency environment, this is complicated by questions of materials, standards, and culture that are typically not present with engineers and architects are working in familiar environments. Do designers specify standard construction materials and international building codes or Unified Facilities Criteria (UFC), or do they go with local materials without formal building codes? Refer to Glenn (2012, 154) and the excerpt below from McArdle (2011) for examples illustrating this point. Do designers introduce more advanced and more capable (and sometimes more fragile) yet unfamiliar technologies or employ simpler, robust, familiar concepts? For designers, the guiding principle should be that it is their project not ours, and it should be done their way and not ours.

> "During my year in Afghanistan, I sat for hours in meetings with local officials in remote mountain and desert locations, sweating or freezing — depending upon the season — inside concrete and cinder-block schools and police stations built with American aid. These projects are required to adhere to international building codes, which do not permit the construction of traditional earthen structures. These structures are typically built with cob — a mixture of mud, sand, clay and chopped straw molded to form durable, elegant, super-insulated, earthquake-resistant structures. With their thick walls, small windows and natural ventilation, traditional Afghan homes may not comply with international building codes, but they are cooler in summer and warmer in winter than cinder-block buildings. They also last a long time. Some of Afghanistan's oldest structures, including sections of the defensive wall that once surrounded the 2,000-year-old Silk Road city of Balkh, are made of cob and rammed earth." (McArdle 2012)

Finance

Project *finance* involves "paying now" and "paying later," and both payments must be considered during project planning and design. Paying now involves paying for design, construction, and commissioning, while paying later refers to the essential operation and maintenance of the completed project. Planners must also understand the funding mechanism available, since U.S. project funds are often allocated by Congress for specific purposes and with specific limitations. For instance, Figure 23 shows U.S. funding programs for Iraq's reconstruction. Reprogramming funds from one funding source to another is often difficult if not impossible. Restrictions on the duration of funding also shape project design. Mechanisms must also be in place to execute the funding. In contingency conditions, planners must also consider how money will be disbursed. Banking systems have often collapsed and electronic transfers may be impossible. The resulting cash-based system is highly subject to corruption and theft. It is for this reason that the enabling fundamental of finance may need to precede major development projects.

Figure 23. U.S. funding for Iraq reconstruction as of 30 September 2012 (SIGIR 2013, 56).

TABLE 4.1
U.S. Funding for Iraq Reconstruction, as of 9/30/2012
$ Millions

	Appropriated	Obligated	Expended
Major Funds			
Iraq Relief and Reconstruction Fund (IRRF 1 and IRRF 2)	20,864	20,343	20,076
Iraq Security Forces Fund (ISFF)	20,194	19,569	18,762
Economic Support Fund (ESF)	5,134	4,578	4,199
Commander's Emergency Response Program (CERP)	4,119	3,728	3,728
International Narcotics Control and Law Enforcement (INCLE)	1,313	1,155	989
Subtotal	**51,624**	**49,373**	**47,754**
Other Assistance Programs			
Migration and Refugee Assistance (MRA) and Emergency Refugee and Migration Assistance (ERMA)	1,501	1,494	1,339
Foreign Military Financing (FMF)	850		
Natural Resources Risk Remediation Fund (NRRRF)	801	801	801
Iraq Freedom Fund (Other Reconstruction Activities)	700	680	654
P.L. 480 Food Aid (Title II and Non-Title II)	395	395	395
International Disaster Assistance (IDA) and International Disaster and Famine Assistance (IDFA)	272	261	261
Democracy Fund (DF) and Human Rights and Democracy Fund (HRDF)	266	266	262
U.S. Contributions to International Organizations (CIO)	179		
Iraq Freedom Fund (TFBSO)	174	86	65
Nonproliferation, Anti-terrorism, Demining, and Related Programs (NADR)	163	62	62
Department of Justice (DoJ)	133	121	119
Child Survival and Health Programs Fund (CSH)	90	90	90
Education and Cultural Exchange Programs	46		
Overseas Humanitarian, Disaster and Civic Aid (OHDACA)	27	27	10
International Affairs Technical Assistance	16	16	14
International Military Education and Training (IMET)	11	9	6
U.S. Marshals Service	9	9	9
Alhurra-Iraq Broadcasting	5	5	5
Subtotal	**5,638**	**4,323**	**4,093**
Reconstruction-related Operating Expenses	**2,937**	**1,152**	**1,085**
Reconstruction Oversight	**445**	**340**	**333**
Total	**60,644**	**55,187**	**53,265**

Failure to properly plan operational and maintenance funding for a project through billing and receiving customer payments and/or taxation-based government funding means that design and construction funding was simply an inefficient form of transfer payments. It is this failure to properly plan for future funding that lead the SIGAR (2012a) to report:

> Because implementing agencies did not develop adequate sustainment plans, and project sustainment relies on Afghan entities with questionable capacity and on unidentified and unfunded projects or projects with completion dates beyond 2014, Congress and the U.S. taxpayers do not

have reasonable assurance that projects implemented using fiscal year 2011 AIF* funds will be viable or sustained by the Afghan government after completion.

Build

Once conceived, financed, and designed, the project must be built. Determining who builds a project is affected by many factors. In contingency conditions, local contractors often do not have the capacity to execute large projects. U.S. forces that show up with money to spend often find that every sheik's brother is a contractor—some are competent, but many have neither knowledge, experience, equipment, skilled workers, nor working capital to be effective. Engaging local contractors has the potential competing aspects of (a) local capacity development which supports stability objectives and (b) poor quality construction due to unfamiliarity with the construction technique and material (our fault) or unskilled contractors (thus the need for capacity development). For larger projects, local contractors often lack the capacity to manage the project which results in the use of large U.S. or multi-national firms. Figure 24 show firms performing significant work in Iraq's reconstruction. Many of these names are familiar to engineers, architects, and planners and with two exceptions, none are local contractors. While this approach hopefully secures a complete, high-quality product, it does little for capacity development and host nation social and economic development.

Figure 24. Major firms performing Iraq reconstruction (SIGIR 2013, 54).


FIGURE 3.11
Selected Major Contractors: IRRF, ISFF, and ESF
$ Millions

Because the U.S. government did not track all funding by project and contractor, a comprehensive list of awards cannot be compiled.

IRRF
Total Obligations: $20.34B
36%

Contractor	Cumulative Award Obligations
Bechtel Corporation	2,465.1
Fluor/AMEC, LLC	973.7
Parsons Global Services, Inc.	697.1
Parsons Iraq Joint Venture	575.4
URS Group, Inc.	541.9
Kellog Brown & Root Services, Inc.	485.6
Research Triangle Institute International	386.1
Symbion Power LLC	285.4
Environmental Chemical Corporation	276.3
Sturm, Ruger & Company, Inc.	259.0
Washington International/Black & Veatch	240.3
Iraqi Contractor (4389)	216.9

ISFF
Total Obligations: $19.57B
27%

Contractor	Cumulative Award Obligations
AECOM Government Services, Inc.	1,522.1
Environmental Chemical Corporation	816.3
Raytheon Company	405.9
Tetra International, Inc.	403.1
American Equipment Company (AMERCO)	391.7
Iraqi Contractor (5300)	372.1
O'gara-Hess & Eisenhardt Armoring Company	283.4
Ohio Ordnance Works, Inc.	281.2
URS Group, Inc.	249.0
Versar, Inc.	219.0
Innovative Technical Solutions, Inc.	214.8
Navistar	206.4

ESF
Total Obligations: $4.58B
60%

Contractor	Cumulative Award Obligations
International Relief and Development, Inc.	703.7
Research Triangle Institute International	444.3
Louis Berger Group, Inc.	385.1
Management Systems International, Inc.	387.1
CHF International	226.7
Development Alternatives, Inc.	161.8
Bearing Point, Inc.	92.5
AECOM International Development, Inc.	84.3
ACDI/VOCA	82.3
University Research Company, LLC	72.9
Wamar International, Inc.	69.6
Parsons Brinckerhoff, Inc.	59.0

In a contingency environment, construction projects (large or small) offer a potential for corruption which must be considered by planners and leaders. Corruption may be as simple as favoring particular individuals or groups in contract awards or as complex as schemes to defraud. Because

* Afghan Investment Fund

the enemy is always considered in tactical plans, potential corruptors must be considered in a project development plan and appropriate anti-corruption measures must be adopted. Failure to manage corruption often leads to project failure (Glenn 2012). The significance of corruption to infrastructure development can be assessed by its position in after action reviews (AARs)—the word corruption (or anti-corruption) appears 66 times in Dr. Glenn's report (Glenn 2012) and 54 times in the SIGIR's final report (SIGIR 2013).

Transfer

On a pre-deployment site survey, MG David G. Perkins said, "Sir, you know what I'd really like to know is not what's next but what's last. If you tell me what's last, then I'll know what's next" (Glenn 2012, 261). In 1993, LTC Tom Gross said during an AAR at Fort Hood, "The guy that said start at the objective and plan backwards was a really smart guy" (Gross 1993). What is last, in infrastructure development, is the transfer of the project to the receiving entity. The requirement to transfer will shape what is designed, the level of technology employed, how it is constructed, and every other detail for the project. Failure to begin with *Transfer* in mind will probably lead to a project that the host nation will find socially, politically, culturally, and technologically inappropriate and unsustainable. Early failures in project transfer planning led to it begin addressed in U.S. Public Law 110-252, Subchapter C, Section 1402 (a) which makes the following statement (11oth Congress 2008):

> None of the funds appropriated by this chapter for infrastructure maintenance activities in Iraq may be made available until the Secretary of State certifies and reports to the Committees on Appropriations that the Governments of the United States and Iraq have entered into, and are implementing, an asset transfer agreement that includes commitments by the Government of Iraq to maintain United States funded infrastructure in Iraq.

Transfer plans relate strongly to *Finance* above and to *Operate* and *Maintain* below.

Operate

Though the switch may be turned on or the ribbon cut by the United States, the supported nation will operate the infrastructure development project. Infrastructure development promotes stability, initially through providing employment during the construction but mainly by the service provided by the facility during its useful life. The inability to operate a facility successfully often causes more harm to local government legitimacy and U.S. credibility than having no facility at all.

Maintain

Without maintenance, operation does not continue. The inability to sustain the operation of a facility through properly funded maintenance often causes more harm to local government legitimacy and U.S. credibility than having no facility at all. (Yes, the same phrase is repeated here deliberately for emphasis.) Operation and maintenance are both funded through the *Finance* mechanism described above and shaped by the social, political, and economic dimensions of the infrastructure environment.

4.6 Infrastructure Resilience Model

Following the events of 11 September 2001, infrastructure protection became a topic of interest in our national conversations. Next, nation-building activities in Iraq and Afghanistan strongly influenced the Defense sector's interest in infrastructure protection, resilience, and restoration. The hurricane season of 2005, which produced Hurricanes Katrina, Rita, and Wilma, reminded us that natural hazards are more common than terrorist attacks and typically have more wide-ranging effects. These events combined to draw our focus towards infrastructure resilience as a key element in infrastructure planning and management.

4.6.1 Defining resilience

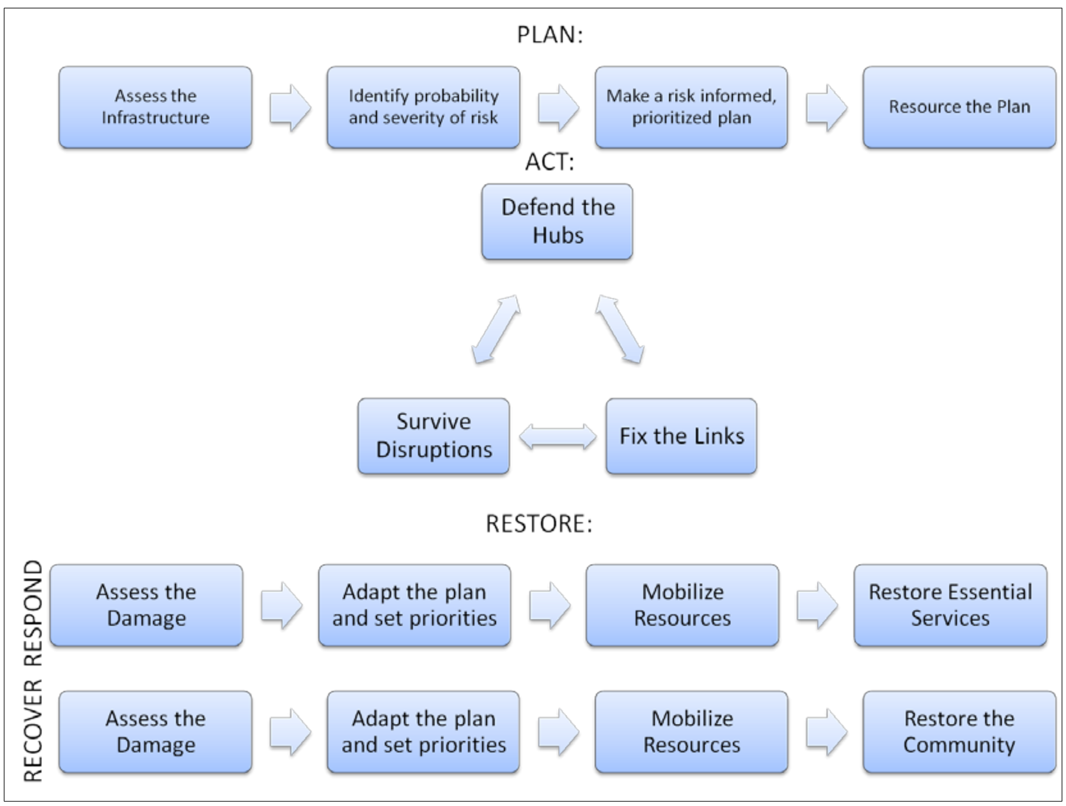
While definitions abound for infrastructure resilience, the one most consistent with the West Point Infrastructure Models is that offered by The Infrastructure Security Partnership (TISP): "a capacity to absorb or mitigate the impact of hazard events while maintaining [or]* restoring essential services" (TISP 2010).The TISP definition acknowledges that infrastructures must provide services under both normal and adverse conditions. The pairings of "absorb–mitigate" and "maintaining–restoring" acknowledge the idea that some things are so essential, they must continue

* The original TISP definition is "maintaining and restoring." The authors contend that if an essential service is maintained, then it need not be restored, and that if it must be restored, then it was not maintained. Thus, this report's authors believe the more applicable conjunction is "or."

to operate in adverse conditions (e.g., a Level-1 trauma hospital), while others will fail and be restored after the event.

Although no one likes the idea of acceptable damage, the realities of terrorist threats, environmental hazards, infrastructure scale, and limited finances mean that everything cannot be protected against every eventuality. With these realities in mind, the Infrastructure Resilience Model includes three overarching components: Plan, Act, and Restore (Figure 25). These components provide a framework for the design of resilient infrastructures that incorporate risk management, engineering design, emergency response, and rationally sequenced recovery. The *Plan* and *Restore* phases use existing, recognized techniques and doctrine, while the *Act* phase provides a concept for improving resilience across all elements of infrastructure as outlined in the Infrastructure Component Model.

Figure 25. Components of the Infrastructure Resilience Model.



4.6.2 Plan phase

The *Plan* phase calls for the use of risk-based decision-making models that take into account the probability and severity of hazards, the value of infrastructure components and systems, and the limited nature of the resources needed to improve resilience. The result of this phase includes two essential outcomes: (1) a plan that accounts for the human, cyber, and physical aspects of an infrastructure and improves the infrastructure's ability to absorb or mitigate adverse events and/or maintain or restore essential services, and (2) the financial, equipment, and human resources necessary to execute the plan. The *Restore* phase covers all aspects of response and recovery as outlined in the *National Incident Management System* (FEMA 2008a), the *National Response Framework* (FEMA 2008b), and the *National Disaster Recovery Framework* (FEMA 2011).

4.6.3 Act phase

The heart of the Infrastructure Resilience Model is the *Act* phase, which calls for defending hubs, fixing links, and surviving disruptions; it is a process well informed by the *Plan* phase, and one which should include network analysis. Hubs are nodes critical to the operation of the infrastructure and typically represent a means of *Generation* or highly connected elements of *Bulk Transmission*, such as transformer stations. Hubs tend to be discreet locations, few in number, and expensive to build or replace. Links are the means of connection between hubs, less critical nodes in the infrastructure, and *Users*. Links are typically elements of *Bulk Transmission* and *Distribution*, including items like electrical transmission and distribution lines, water mains, and rail lines. Links tend to be long, numerous, exposed, and hopefully at least moderately redundant. Whereas hubs (power plants, transformer stations, water treatment plants) tend to be in locations with controlled access, links are typically in public view, even public contact. *Users*, the reason the entire system exists, are nodes in network terminology, and are typically on the end of a distribution link. Thus, an infrastructure network can be described in terms of hubs, links, and users; the *Act* phase of the Infrastructure Resilience Model addresses each of these three items.

First, defend the hubs

By their nature, hubs are essential to the overall functioning of an infrastructure system. They are typically expensive, major installations that cannot be quickly replaced. Their loss or damage causes the infrastructure network to fragment, cascade, or cease to function completely. Defending the hubs is mainly a matter of proper design in terms of physical, cyber, and human elements. Based on the threats and hazards determined in the

Plan phase, the hubs are designed to withstand environmental loads, acts of aggression, and computer hacking. In short, they are designed, built, and operated to be *Tough*, as described in the Infrastructure Assessment Model.

Second, fix the links

Links are distribution elements whose length is measured in miles or thousands of miles. Because of this scale, they cannot effectively be defended against all threats and hazards. The typical solution is to put in place the manpower, equipment, materiel, and procedures to prioritize and repair damaged links as quickly as possible. Additionally, because a break in a link can isolate portions of an infrastructure, systems must possess sufficient redundancy so that some loss can be absorbed without widespread failure. This preparation addresses the *redundant* aspect of the Infrastructure Assessment Model. Redundancy can be achieved either by creating alternate paths for transmission and distribution or by rapidly repairing the existing paths.

Third, survive the disruption

The purpose of defending the nodes and fixing the links is to restore service to the *User* as soon as possible. However, the *User* is an element in the infrastructure and has a major role in resilience. The third element is for the *User* to survive the disruption. Users must possess sufficient individual resources such as training, equipment, facilities, and social networks to allow them to survive for the time it takes to repair the links. Users who can survive for 3–10 days on their own allow resources to be concentrated on restoring essential services and thus, speed the response and recovery for all.

The following highlighted vignette about restoring Iraq's oil and gas industry is summarized from the SIGIR 2013 report (83–86) and illustrates real-world elements of the *Act* Phase.

> The United States tried to focus on fixing the oil and gas industry so that it could export oil. The United States went so far as to let the largest-ever sole-source contract in the government's history. Oil is most effectively transported through pipelines. Those pipelines were mostly in place before the war started. With the necessary repairs completed, the pipelines should have been able to export the desired oil. Since pipelines traverse large distances, they are hard to protect. Those pipelines would be considered links that needed to be fixed in the case of a disruption. They are links (and not critical nodes) because of their inability to be defended. With continuous insurgent attacks, those links were continuously severed. The final solution: protect ALL of the critical pipelines. In essence, this made the links into critical nodes.

One element not addressed in this construct is those nodes which are neither hubs nor users. This could be a less critical electrical substation, one of six water towers, or a redundant pumping station. These nodes receive the same treatment as links—plans and procedures for rapid repair. This is an appropriate approach because the loss of these nodes has a limited effect on the network, and they are often too numerous to be economically defended. Infrastructure professionals should recognize that a particular asset is often both hub and user. For example, a drinking water treatment plant is a hub in a water system and a user in the electrical system; the plant must be defended against the effects from natural disasters, terrorism, vandalism, deterioration, and accidents and supplied with backup generation and fuel to survive disruptions in the electrical grid.

4.7 Summary

These five models provide an integrated approach to infrastructure. The Infrastructure Environment Model builds an understanding of all the factors that shape the infrastructure. The Infrastructure Component Model allows one to visualize and describe an existing or proposed infrastructure in terms of its subordinate functions. The Infrastructure Assessment Model provides a means to understand and characterize the quality of the infrastructure. Once the environment and the infrastructure are visualized, described, and understood, the remaining models support achieving the Army's doctrinal missions. The Infrastructure Resilience Model provides a mechanism for establishing a robust response before, during, and after an adverse event by ensuring the infrastructure is tough, redundant, and prepared. The Infrastructure Development Model provides a mechanism for assembling projects which perform the functions of the Infrastructure Component Model into programs which deliver the desired service and meet the need.

5 Establishing Credibility for the Models

5.1 Verification, validation, and credibility

Before a community will adopt a model, confidence that the model is useful for its intended purpose must be established through a documented regimen of verification, validation, and accreditation. Verification determines that the model meets the developers' conceptual description and specification. Validation measures the degree to which the model is an accurate representation of the real world that is appropriate for the purpose of the model. Accreditation is a formal certification that the model is acceptable for a specific purpose. Verification, validation, and accreditation can be addressed by three questions: "Did we build it correctly, did we build the right thing, and does it meet my needs?" (MSIAC 2013).

Because these models are frameworks for understanding, visualizing, and describing complex infrastructure systems and are intended to be broadly applied across multiple infrastructures and broadly used by engineers, planners, managers, and citizens, it is unlikely that the models will ever receive formal accreditation. Verification and validation of conceptual and social models such as those proposed in this technical report is also difficult because of the lack of quantifiable measures. Under these conditions, it is more appropriate to establish the credibility of the model. Establishing the credibility of a conceptual model seeks to answer the same questions as verification, validation, and accreditation, but does so through dissemination in education and professional discourse, case studies, and subject matter expert evaluations (Macal 2005) What follows are different measures that point to the credibility of the proposed models.

As of the writing of this report, these models have been taught to 600 students at the U.S. Military Academy at West Point over eight academic terms. To teach these models in a new course required a curriculum change to be approved by the institution's curriculum committee, and this was done with the concurrence of the department's Civil Engineering Advisory Board, a process which speaks to accreditation—both the models and the course they are taught in meet a need. The first cohort of students trained in these models graduated in May 2012 and is now serving in the Army; assessment questions related to the models will be included in subsequent graduate surveys. Immediate impacts, however, have been observed. We see students applying the Infrastructure Component Model in circumstances we did not expect: students have used it to successfully characterize and assess complex, multi-system infrastructure settings as part of field exercises. More specifically, a political science student used it in a highly respected national-level 2011 Model United Nations competition as a basis for a resolution on long-term development. As a result, he won “Outstanding Delegate,” a clear indicator that a respected panel of experts in the humanities regarded the models as effective. One strong qualitative measure of the impact of these models and the course that presents them is an assignment where students must draw a picture demonstrating their understanding of infrastructure. The picture in Figure 26 clearly shows a student who understands the impact of infrastructure on her life as a citizen and an Army officer. Note that the drawing is technically correct: the electric line is a three-phase (wye) residential distribution system as discussed in the class. These observations allude to verification in that the models are satisfying the design characteristics described above and to validation in that they are useful in solving real problems.

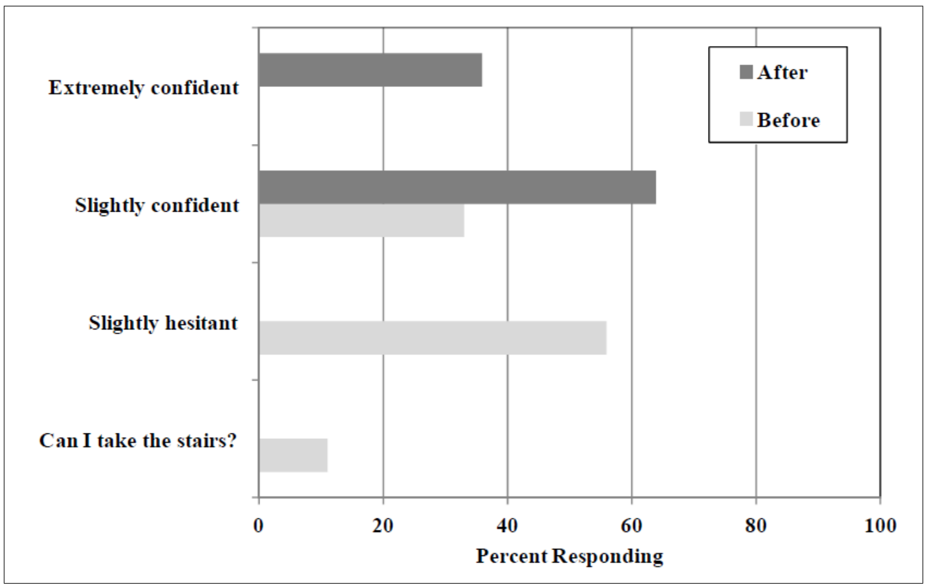
Figure 26. Infrastructure from a future lieutenant's perspective (Illustration by LT Colleen D. Harrison, U.S. Army, May 2012).

During a four-hour seminar in 2012, these models were presented to 225 students at the U.S. Army Engineer School Captain’s Career Course, a rigorous six-month course to prepare captains to serve as company commanders and staff officers. As a result of the initial presentation and a careful professional review of the content, the seminar has been adopted as a standard element in the curriculum and is now presented five or six times each year. The director of the Career Course assessed the seminar by stating, "I think the information you provided was exactly right for what engineer company commanders need to know (or at least be thinking about), and ... I will be delivering a modified lesson package to the Australian Combat Officers Advanced Course next year" (McMurray 2012). Following a subsequent presentation, one captain stated, "You made quite an impression, and to this day, my classmates are still talking about what a great class that was" (and in a group of cynical captains, that is quite an accomplishment) (Barry 2013). This is further evidence for both the validity and accreditation of the proposed models.

During development, the models have been presented extensively in peer-reviewed papers at professional conferences (Hart 2010, 2011, 2012; Hart et al. 2011; Klosky 2012) as well as to then-president of ASCE, Blaine Leonard. In this process, the authors have strongly encouraged feedback and have been deliberate and careful in noting that feedback and in their observations of how the models are received. The result is remarkably consistent; when the Grizzly Bear illustration in Figure 20 is shown, everyone laughs, but as the models are described, the humor subsides and most pull out a pad and start taking notes. Feedback from each session has been strongly positive, with many listeners indicating that the content is "on the mark" and "of considerable value." This consistently positive feedback speaks to the credibility of the models.

The credibility of the models has been further established in a seminar presentation at the Department of Civil and Environmental Engineering of the New Jersey Institute of Technology (NJIT), which offers a Master of Science degree in Critical Infrastructure. Present at the seminar were eight doctoral candidates, two guest industry professionals, and six professors (one of whom was awarded the 2011 Henry L. Michel Award for Industry Advancement of Research). To assess achievement of the model objectives, this situation was posed to the audience: You are in an elevator on the 30th floor with Governor Christie. He says, "So, you're a civil engineer. Listen, I'm having some issues with the electrical infrastructure and I don't really understand it. Can you explain it to me before we get off the elevator?" Participants were then asked to assess their confidence in being able to answer this hypothetical question both before and after learning about the models described in this paper. The results shown in Figure 27 clearly indicate that these highly competent engineers entered the seminar with technical knowledge of the infrastructure but without confidence in their ability to convey that understanding to a political leader. Exposure to the infrastructure models did not increase their technical knowledge, but rather provided the framework necessary for them to confidently explain a complex infrastructure system to a nontechnical audience.

Figure 27. NJIT survey results of engineer confidence levels to describe infrastructure to a nonprofessional before and after models presentation (Hart, Klosky, and Katalenich 2013).



These models are also gaining positive exposure and peer review through the American Society of Civil Engineers. This report draws heavily on a peer reviewed journal paper, Conceptual Models for Infrastructure Leadership, published in the *Journal of Engineering and Management* (Hart et al. 2013), presented in an ASCE webinar of the same title sponsored by the Committee on Critical Infrastructure (CCI) and attended by 60 participants (Hart and Klosky 2013), and presented in an invited presentation that was attended by about 100 participants at the 2013 Annual Convention (Klosky et al. 2013). As this technical report is focused on the application of these models to military contingency situations, ASCE's CCI is preparing a report to adapt them for civilian use to foster vertical communication from users through municipalities, to states, and the federal government.

These examples of coursework, presentations, and publication history strongly indicate that the models are credible tools which provide a shared framework for creative, critical, complete, and compelling infrastructure analysis and discussion among a wide variety of stakeholders. That said, it is expected that the models will improve as they are presented to wider audiences of increasingly varied backgrounds, benefiting from the critiques and observations of those audiences.

5.2 AAR examples of where the models could have been used

Another approach to validating (did we build the right thing?) the models is to ask the question, “How could these have been used in actual circumstances to aid planning and decision making?” The examples below are real-world problems. With only initial information provided, problems are then analyzed by using an appropriate model. The authors propose that the models provide a useful tool for understanding, visualizing, and describing the issues and potential solutions. The reader may determine if the application was successful.

5.2.1 Example 1: The lieutenant and the micro-hydro project

The email message text that is highlighted below was sent by a lieutenant working in a battalion S-3 shop as his unit was preparing to deploy. Having had the assignment trickle from battalion commander to S-3, to Assistant S-3, and finally to him, the lieutenant contacted his former West Point faculty member to request assistance. Considering the issue of micro-hydro power, the following application of the Infrastructure Component Model is offered as a starting point for addressing this challenge.

> My unit is deploying on the XXrd to YYYYYYY. We want to bring the population closer to the government through stimulating the economy. In our AO we see two ways of doing this relatively quickly: using alternative energy to power homes and businesses, and successfully mining the rock quarry.
>
> In regards to energy, we are specifically looking at micro-hydropower. Over fifty sites have been identified in the province to be compatible for a micro-hydropower plant. We were wondering if anyone at C&ME had any experience or expertise in the subject, or might be able to advise us as we develop the sites.
>
> The marble quarry is a huge potential for economic growth for both the region and the country. Presently the locals are using UXOs to mine marble, then exporting the raw rock to Pakistan to be processed into finished marble. We are interested in any suggestions the department might have for us to help the local population of Nangarhar safely mine and potentially process the marble.
>
> I know the information I have is vague, but until we get there, we do not know exactly what the sites look like and what is happening at each of them. Mostly we were wondering if anyone had experience with mining and micro-hydropower (perhaps a professor did thesis on micro-hydropower or mining techniques), and if they could advise later once we get more information. Any help would be much appreciated and would be helping us complete our mission. (Private communication with authors- name withheld, September 2010.)

Use

Why does the village need electricity? What are the current uses of electricity? What are the future desired uses of electricity? Inductive, capacitive, and resistive loads all impact the system differently. What is the peak power demand? What is the energy demand? Does giving electricity to one village and not the neighboring villages have a stabilizing or de-stabilizing effect on the region?

Generation

How much potential energy is available at the generation point? (The answer is a function of elevation head and volume of water.) Where will the water go once it flows through the generator? Will moving water through a generator divert water from other uses? Are there environmental impacts to diverting the water? Does diverting the water to the generator change the direction of flow of the water and impact another village downstream? How far is it from the point of generation to the point of use? In determining the feasibility of this project, this last question is the most important. If the generator and the village are within a couple of hundred meters of each other, then the electricity can be generated and used at the same voltage. If the distance is longer, then a bulk transmission and/or other type of distribution system will be required. This development means transformers and other equipment, and the problem just got far harder than a maneuver battalion can manage.

Bulk transmission

If the unit needs this project, then it isn't "micro" anymore!

Distribution

How will the generator be connected to the users? Who gets connected and who does not? What is the impact of electrical connection or lack of connection on the village and regional stability? How will the village allocate power and energy to individual users? (When the power arrives, if everyone gets a refrigerator, air conditioner, and satellite TV, then the system will be quickly overloaded.)

Waste management

Do not say, "It's hydro—how can there be waste?" Is a penstock used to move the water from its natural location to the generator? Where does the water go once it leaves the generator?

Coordination

How will the system be maintained? Will anyone be charged for the electricity? How much? Who collects the payments? Who becomes the local power authority? How do the operators keep the turbine from silting up? Who provides training for the operators and maintainers? Who trains the second set of operators and maintainers when the first set departs for better paying jobs elsewhere?

This application of the Infrastructure Component Model demonstrates its applicability to a real problem. It allows the problem to be broken down into manageable parts without losing the connection of those parts to the whole. In the initial planning stages, the Infrastructure Component Model allows the formulation of questions to aid understanding. As these questions are answered, the model provides the ability to visualize, and then describe, a complete system that will both deliver electricity to a village and promote stability in the area.

5.2.2 Example 2: Assessing Hurricane Sandy by using the Infrastructure Resilience Model*

Hurricane Sandy was a high-stress event that had major impacts on the infrastructure systems of the American East Coast, especially the New York area. Classified a Category One storm when it made landfall near Atlantic City, New Jersey, on 29 October 2012, it caused billions of dollars in damage to New York area infrastructure (Sharp 2012).

The second-largest storm on record, Hurricane Sandy produced “hurricane force winds (at least 74 mph) extending 175 miles from its center” that caused damage to buildings, businesses, and homes throughout the entire East Coast. This hurricane was reported as “one of the costliest natural disasters on record in the United States, according to IHS Global Insight” (Sharp 2012). Hurricane Sandy set multiple records including the lowest barometric reading ever recorded for the United States and the highest storm surge ever recorded for New York City. The storm caused massive power outages: on 30 October 2012—1.7 million people in New Jersey and 1.2 million people in New York were without power (Malloy 2012). Major transportation avenues were affected such as the subway and tunnel system, and businesses were shut down for extended periods of time. The storm also caused considerable loss of life, as shown in Figure 28.

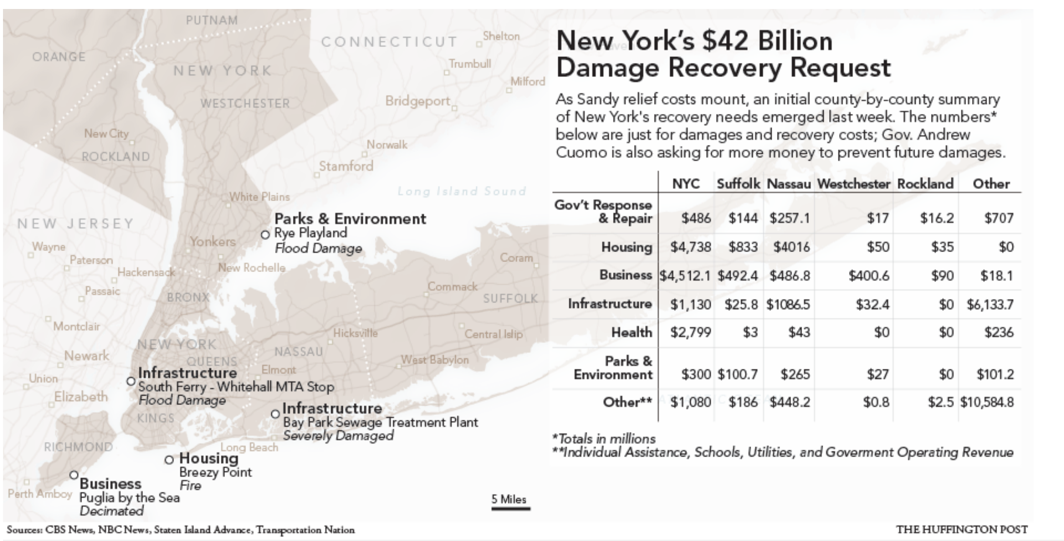
* This section was originally written by Peter Noto in April 2013 as a class project for CE490, “Designing Resilient Infrastructures.”

Figure 28. Deaths from Hurricane Sandy (Blake et al. 2013).

State	Direct Deaths
New York	48
New Jersey	12
Connecticut	5
Pennsylvania	2
Virginia	2
New Hampshire	1
West Virginia	1
Maryland	1
Total	72

As shown in Figure 29, Gov. Andrew Cuomo of New York requested a total of $42 billion to address the statewide damage caused by Hurricane Sandy.

Figure 29. New York's request for federal recovery funding (Sledge 2012).



This section will map the events of Hurricane Sandy to the *Act* phase—defend the hubs, restore the links, survive the disruption—of the Infrastructure Resilience Model. This section will demonstrate that the Infrastructure Resilience Model is a valid organizational tool for organizing and understand past events, which implies that it may also be useful for predictive organization, understanding, and strategy development. This is an inductive argument in that the conclusion is probable, not certain; the certainty of its usefulness can only be established after someone has used it to prepare for an event which later occurs.

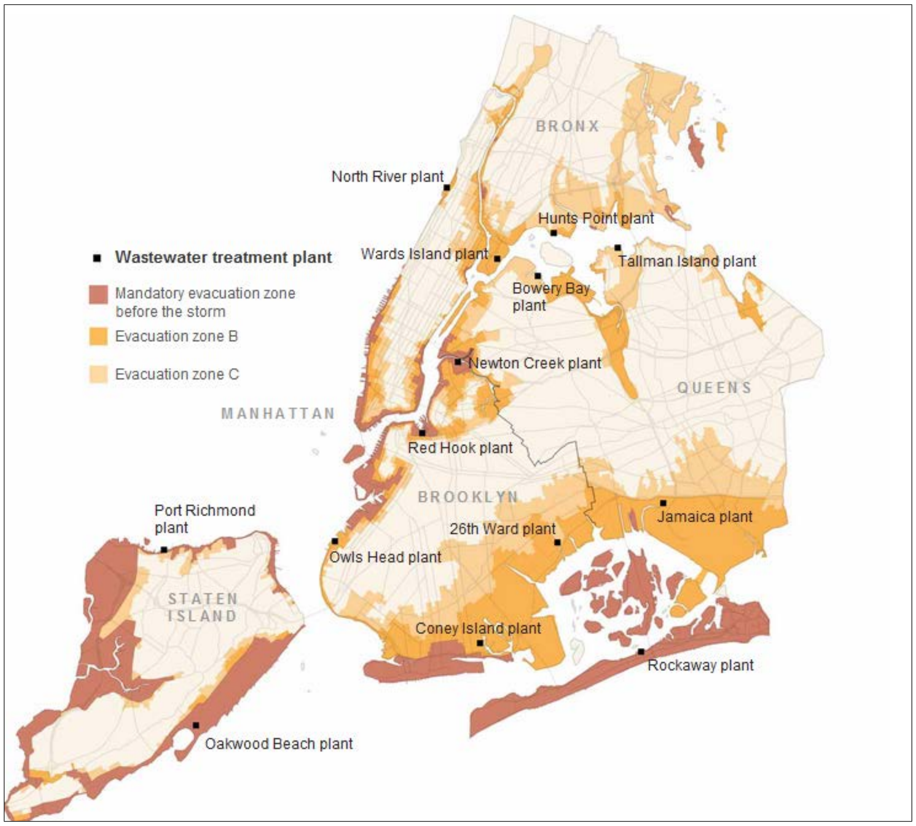
Defend the hubs

As explained in the Infrastructure Resilience Model text (Section 4.6), hubs are typically expensive, major installations that cannot be quickly replaced. Their loss or damage causes the infrastructure network to fragment, cascade, or cease to function completely.

Within the healthcare infrastructure, hospitals are hubs. During Hurricane Sandy, numerous hospitals were affected including New York University (NYU) Langone Medical Center which lost power and was forced to evacuate 300 patients. "The Hospital had at least two backup generators: one on in the basement and one on the roof, according to a spokeswoman. But basement flooding caused one generator to fail, cutting off the fuel supply to the other" (Moise and Lupkin 2012). Another example is the Bellevue Hospital, which also was forced to evacuate some of its patients after it lost power due to its generators failing. Several other hospitals, including the Coney Island Hospital, and the Palisades Medical Center also lost power and were forced to evacuate (Moise and Lupkin 2012). The loss of the hospitals forced patient evacuations and limited emergency treatment options for first responders. This failure in "defending the hubs," caused major issues within the medical service infrastructure.

Moreover, wastewater treatment facilities also fit the definition of a hub. "Five of New York's fourteen wastewater treatment plants are located in the lowest lying areas of the city, within the mandatory evacuation zone" (New York Times 2012). The storm surge caused many of these plants to overflow and as a result, storm water was "flowing directly into New York's water ways... and into flooded streets and buildings" (New York Times 2012). The Bay Park Sewage plant in Nassau County was "overwhelmed by 12 feet of water, [and] spewed hundreds of millions of gallons of partially treated sewage into nearby waters" (Sledge 2012). Figure 30 shows a map of the wastewater treatment plants located within the New York metropolitan area and their relationship to evacuation areas.

Figure 30. Wastewater treatment plants in New York City related to Hurricane Sandy evacuation areas (Sledge 2012).



This outcome also exemplifies a failure in "defending the hubs." The majority of wastewater treatment facilities were not equipped to handle the volume of water due to Hurricane Sandy, and as a result, metropolitan area systems overflowed and caused service problems for the entire area.

Subway stations also are important hubs within the transportation network of the New York metropolitan area. Several subway stations were flooded, resulting in cancellation of service for an extended period following the storm. For example, the "South Ferry-Whitehall Street subway station alone will require a $600 million restoration," and it was almost completely destroyed by the storm (Sledge 2012). Numerous other subway stations were affected in similar ways, with flooding resulting in station closure and service suspension. This outcome shows a failure to defend the hubs within the subway infrastructure.

Airports can be classified as hubs as well. Hurricane Sandy forced the closure of the three major airports within the New York metropolitan area: Newark Liberty, John F. Kennedy International, and LaGuardia airports.

This closure was a result of the severe flooding of the tarmacs and impossible flight conditions. LaGuardia Airport was especially affected, due to its geographic location in Flushing Bay in the borough of Queens. Hurricane Sandy "forced the cancellation of 9,250 flights at the region's three major airports grounding 810,000 passengers, the Port Authority said" (Strunsky 2012). Reopening these airports three days after the storm abated is a clear example of successful defense of the hubs. Once the weather and the runways cleared, the airports returned to operation because there was no excessive or long-term damage to their facilities.

Electrical power plants also fit the definition of a hub. Nuclear power plants were especially prepared to deal with the effects of Hurricane Sandy, and they represent a successful example of defending the hubs. "Nuclear power plants are built to withstand hurricanes, airplane collisions, and other major disasters, but safety procedures call for plants to be shut down when hurricane force winds are present, or if water levels nearby exceed certain flood limits" (CBS New 2012). Hurricane Sandy itself did cause a shutdown in some area nuclear power plants, for example the Indian Point Energy Center and Salem Nuclear Generating Station; the plants were well equipped to handle the situation, but the shutdowns were a result of the planned safety features for the plants. Once it was safe to operate, the plants resumed production (CBS News 2012).

Restore the links

As explained in the Infrastructure Resilience Model discussion (Section 4.6), links are long, distributed elements whose size is measured in miles or thousands of miles, and which cannot be completely defended and therefore must be addressed through restoration plans and sufficient redundancy. There were numerous examples during Hurricane Sandy that represent challenges, successes, and failures in restoring the links.

Tunnels may be classified as links according to this model.* There were numerous commuter tunnels within the area affected by Hurricane Sandy. For example, there was major flooding within the Brooklyn-Battery Tunnel, see Figure 31 and Queens-Midtown Tunnel.

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* Another perspective can classify them as hubs. Either way, they are critical elements in the infrastructure of New York City and plans for defense, restoration, or a combination of both are appropriate. By choosing not to defend the tunnels using available technologies like tunnel plugs, a de facto choice to restore them is made, even if not acknowledged beforehand.

Figure 31. Flooding in the Brooklyn-Battery Tunnel (New York Times 2012).

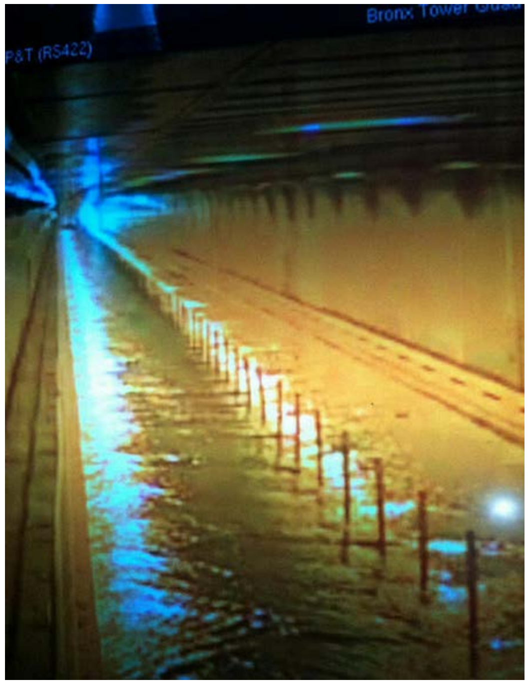
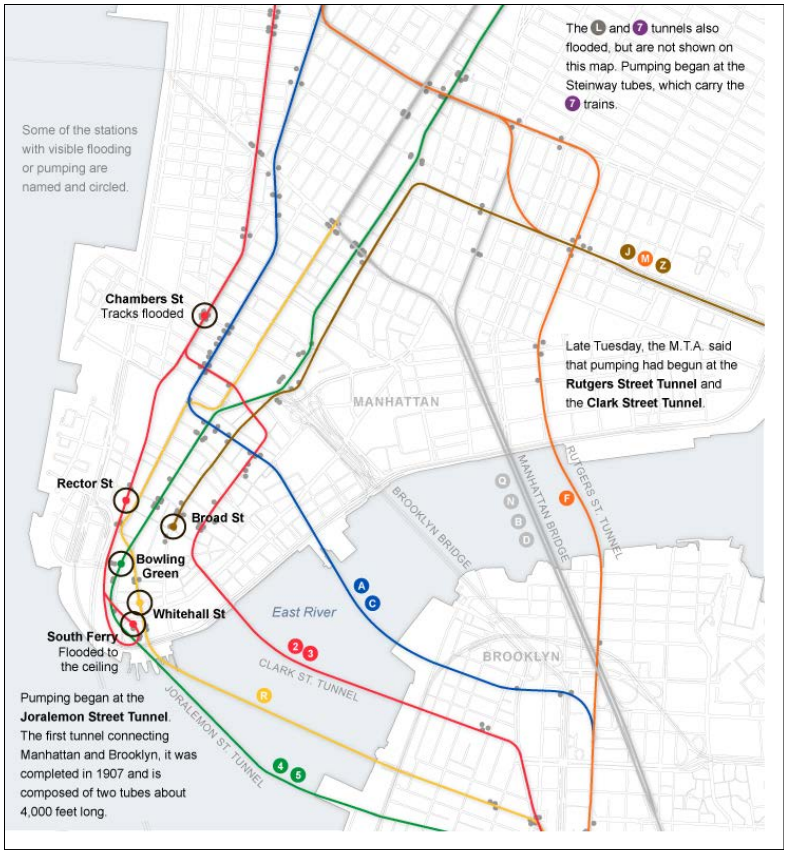


Figure 31 is representative of the type of flooding seen within numerous tunnels throughout the area. “Restoring the tunnels will present one of the most serious challenges to the city; once pumped out, they need to be cleared of sludge and debris” (New York Times 2012). The restoration of the tunnels within the area affected by the storm was a major endeavor. It took about two weeks to restore most of the tunnels with the exception of the Brooklyn-Battery Tunnel, which experienced severe damage by serving “as a drain for Lower Manhattan, filling with nearly 100 million gallons of water” (Rosenthal 2012).

The subway system has a large number of links, and is essential in transporting people throughout New York City and the surrounding area. Subway lines were also greatly affected by Hurricane Sandy. Lines were flooded due to the large storm surge. Figure 32 shows a map of some affected lines within the Manhattan area:

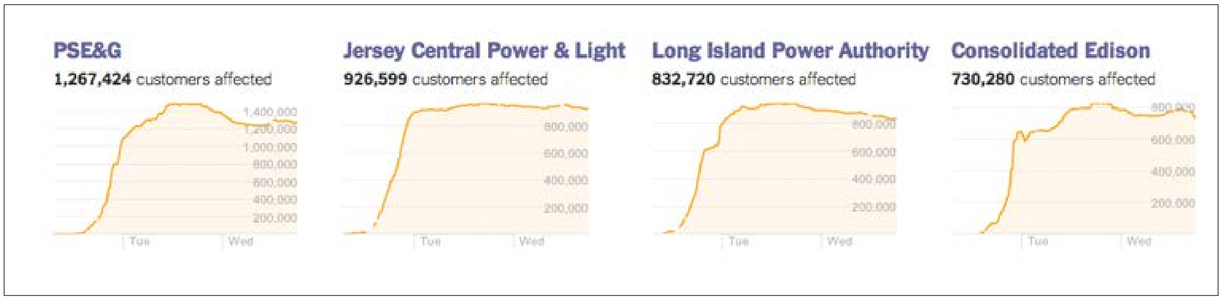
Figure 32. New York City subway lines affected by Hurricane Sandy (New York Times 2012).



Roadways are the classical definition of links and were also heavily affected by Hurricane Sandy. For example, in Ocean City, New Jersey, all the roads into the city were closed due to extreme flooding, effectively cutting off the city (Malloy 2012). Debris left by the storm also resulted in the closure of Route 36 along the Jersey Shore (Celock 2012). Most of the major roadways were reopened by 31 October (Preston 2012), representing a success in effectively restoring these links.

Electrical power lines can also be classified as links and were extremely affected by Hurricane Sandy. The power failures experienced by millions of people were mostly the result of downed power lines. Figure 33 illustrates the number of customers affected just within New York Metro area.

Figure 33. Customers without electricity from Hurricane Sandy (New York Times 2012).



Restoring these electrical power lines was a major problem after Hurricane Sandy. For example, the Long Island Power Authority (LIPA) was severely unprepared to handle the amount of work that needed to be done and took a long period of time to restore power to affected areas. Over 370,000 customers remained without power on 4 November, six days after the storm hit. LIPA was highly criticized for this failure, and the president of LIPA resigned in disgrace (Ruben 2012).

Survive the disruptions

The purpose of defending the hubs and fixing the links is to restore services to customers as soon as possible. Because a disruption in an infrastructure does not disrupt the need for the service, a user in an infrastructure system should be prepared to survive until service can be restored.

Perhaps the most common example of a disruption faced by users as a result of Hurricane Sandy was the loss of electrical power to homes. This disruption was cause by downed power lines in the areas affected by the storm. As stated above, the restoration of these lines took a longer than expected period of time. The result of this delay caused several issues. Many citizens needed gas generators to have power, and this need created a problem exacerbated by the fuel issues described below. Food shortage was also an issue, with grocery stores experiencing shortages as a result of many citizens stocking up on food before the storm.

Another example of a disruption caused by a failure to restore the links was the gas shortage experienced throughout New York and New Jersey. According to Mayor Michael Bloomberg of New York City, "Hurricane Sandy caused significant flooding and damage to petroleum infrastructure throughout the tri-state region causing refineries to shutdown, pumping stations to lose electricity and terminals in the region to close…Even as the region's petroleum infrastructure slowly returns to normal, the gasoline supply remains a real problem for thousands of New York drivers" (Jeltsen 2012).

Due to the power outages, many gas stations did not have power to pump gas, and therefore users experienced severe problems when trying to purchase gasoline. A gas rationing plan was implemented within New York and New Jersey, providing an example of the steps that had to be taken to survive this particular disruption.

Hurricane Sandy also disrupted the functioning of schools within the New York New Jersey area. For example, the Rocky Point school district on the North Shore of Long Island was closed for an entire week after the storm hit, as were most other schools within the area. The school closings were a result of the roadways needing to be cleared, and the lasting power outages in the area.

Conclusions:

Mapping events from Hurricane Sandy into the models demonstrates that the Infrastructure Resilience Model provides a clear framework in order to analyze these types of high-stress events. The model helps present a better understanding of the key events of the storm and how they affected the infrastructure of the area. As demonstrated above, the model is comprehensive, meaning that all three components, defend the hubs, restore the links and survive the disruptions, must be done to have a resilient system. When any one part of the model is fails, the whole system fails, as seen with the electrical grid system during the storm. The power stations (hubs) were generally well prepared to withstand the storm, and they were operational as soon as the storm was over and it was safe to do so. In general, the users were also prepared to withstand the power outages expected by the storm. Where the system failed, however, was in the restoration of the links; the downed power lines caused the blackouts to be extremely severe, and the authorities were not prepared to handle the volume of inoperable lines. Therefore users experienced more of a delay in restoration of service than is desired or tolerable.

Since the Infrastructure Resilience Model can be used to analyze an event in terms of what happened, it follows that the model can also help in planning future events. If an infrastructure system is designed with the components of the Infrastructure Resilience Model in mind, it will be a more resilient system. The model is a good framework for analyzing a system, and as a result, leaders, planners, and policy makers would be better able to plan for the effects of a high-stress event such as Hurricane Sandy when they do occur.

5.2.3 Example 3: Delivering water requires a program, not a project

In 2004, USACE began a project to restore the Nassiriya, Iraq, drinking water system. The plant was completed and turned over to the government of Iraq in 2007 (Aliwi 2007). In 2011, the Commission on Wartime Contracting* reported that the government of Iraq was requesting "American technical and financial assistance for the $300 million, U.S.-funded Nassiriya water-treatment plant, which was built without an assured source of electric power, is frequently off-line, and produces murky water that many locals won't use" (Commission on Wartime Contracting in Iraq and Afghanistan 2011).

When faced with problems such as this one, the Infrastructure Component Model and the Infrastructure Development Model can be used to structure a program with a high probability of delivering the desired service. Beginning with the water infrastructure, consider the elements of the Infrastructure Component Model.

The new water treatment plant is a *generator*—it produces the desired product (water) in bulk. The plant is located on the Euphrates River and is intended to supply the water needs of five cities in Thi-Qar Province. The water infrastructure requires *bulk transmission* piping to move large quantities (in this case a design demand of 240,000 m^3 per day) long distances (110 km of transmission piping), with limited access to reach each of the five cities. Within the cities, transmission piping was connected to existing *distribution* networks to move smaller quantities in shorter distances for connection to the *user* (SIGIR 2010). The users constitute the population, businesses, and industry of the region. *Coordination* in a water infrastructure requires metering, billing, operations, maintenance, personnel training, and SCADA (supervisory control and data acquisition) systems. This paragraph represents a simple "first pass" through the water

* The Commission on Wartime Contracting (CWC), an independent, bipartisan legislative commission established to study wartime contracting in Iraq and Afghanistan.

infrastructure to determine the essential components. Subsequent passes will increase the depth and detail to the required level.

Now, also consider that water infrastructure is dependent on other infrastructures. For example, the water treatment plant and any pumping stations are *users* in the electrical infrastructure. As such, they operate only when the electricity operates unless provided with backup generation. In this case, the backup generator is now a *user* in the fuel infrastructure and operates only when fuel is present. Another consideration is level of backup generation—does it provide full functionality or just enough to meet emergency demands only. Also note that backup generation increases the complexity of the *coordination* function—more equipment, more spare parts, more maintenance, more trained operators and mechanics. Additionally, the water treatment plant is a *user* in the chemical infrastructure and requires, depending on plant design, alum or other coagulant, chlorine or other disinfectant, and soda ash. Absence of any of these means the infrastructure will not function properly or completely. Because it requires trained operators, laboratory technicians, and repairmen, the water system is a *user* in the educational infrastructure. It is also a *user* in the political infrastructure as it depends on local government for metering, billing, and financial management. Again, this discussion provides only a first pass through the dependencies of the water infrastructure on other infrastructures. An otherwise functioning water infrastructure will fail if any of these are interrupted.

Consider now the Infrastructure Development Model. At the program level, the desired service is water. It is a life-sustaining infrastructure as well as being an enabler for broader economic development and societal stability. A successful water program requires multiple projects to achieve all of the items described above. Each project is necessary for the infrastructure to function, but none of the projects are individually sufficient. Only if all projects are successfully completed will the infrastructure function. Consider also that a supporting program to develop the wastewater infrastructure must also be implemented to prevent the water delivered to homes from ending up as sewage in the streets.

The U.S. government program to establish a water treatment infrastructure in Thi-Qar province was unsuccessful and therefore, the program did not achieve its end goals of increasing stability, building confidence in the legitimacy of the government of Iraq, and increasing goodwill toward the

United States. The SIGIR (2010) report on the project included the issues outlined below. While there is no guarantee that using the Infrastructure Component Model and Infrastructure Development Model would have prevented these issues, the italicized text included below maps each issue back to a model element. This mapping to the model indicates that proper consideration of the models would allow anticipation of each of these conditions and lead to appropriate preemptive actions.

- Poor contractor design of the facility because it only allows for only 20% capacity when operated solely with generators which is a common condition with only 4–8 hr of grid power provided each day. *Water treatment plant is a user in the electrical system*.
- Spare parts provided by the USG have been used and more are needed. Obtaining funding for spare parts through the Iraqi government is difficult. *Coordination is function #6 in the Infrastructure Component Model.*
- Distribution network is old and needs replacement, making it the primary reason why water is not reaching all the homes and people are upset. *Distribution is function #3 in the Infrastructure Component Model.*
- Water meters for customers are not present and although bills are sent, they are rarely collected. Disconnecting use behavior from payment means funds are not available for operations and maintenance, and there is no financial incentive to conserve water. *Coordination function–see spare part issue above.*
- USG did not provide a crane for water treatment plant (WTP) staff to use for maintenance. *Coordination function—an essential element for operations and maintenance.*
- SCADA system never worked. *Coordination function*.
- Too many illegal taps into the distribution system by farmers in the Diwayah area, which results in low water pressure (Figure 34). *Distribution and coordination functions.*
- Garraf River is full of weeds which clog the metal screen bars for the raw water intake, limiting the amount of raw water entering the WTP. *Generation is function #1 in the Infrastructure Component Model.*

Figure 34. Illegal taps in the distribution lines, Nassiriya, Iraq (SIGIR 2010).

6 Insufficiency of the Models

These models are proposed as a cognitive framework for thinking critically, creatively, and completely about infrastructure challenges. They support but do not replace the operations research, detailed design, environmental impact studies, and myriad other work necessary to bring an infrastructure program or project to fruition. They are a place to start as well as a place to end—the models can be used to evaluate the completeness of a proposed solution. Any model is useful to the degree that it aids understanding. If it does not increase understanding, then it should not be applied in that particular case or else a new, sometimes general and sometimes case-specific model should be created. The models presented here are useful for most infrastructures under most circumstances, but they will not cover all infrastructures in all circumstances or all aspects of an infrastructure in any circumstance. Therefore, we have developed other models that deal with specific infrastructure instances and suggest that others do the same.

It is illustrative to note that these models have and will continue to undergo development. Appendix B shows the evolution of the Infrastructure Component Model, and other supporting models are explained below.

6.1 Additional models may be required

6.1.1 Transportation model

Consider the application of the Infrastructure Component Model to a road transportation system. A trip may be generated at a home when a family decides to go out to dinner. After pulling out of the driveway, the family will drive on a local, small road(s) which would meet the definition of *distribution*. The family then enters an interstate, which, by definition would be *bulk transmission*. Exiting the interstate for another small road(s) (distribution again), the family eventually reaches the restaurant—*use*. This application of the Infrastructure Component Model works (sort of), but it does not tell us anything about the differences in interstates and local roads. This was the exact problem faced during one lesson of the initial offering of CE350 course at the U.S. Military Academy, resulting in the creation of the “C350 Transportation Model” in the middle of the class.

All transportation systems can be described by four elements: backbone, carrier, commodity, and control. The *backbone* consists of the fixed, physical elements of the system, the *carriers* are the movable things that ride upon the backbone, the *commodity* is what gets moved, and *control* is the laws, regulations, signage, lights, and systems to make the system work safely and efficiently as a unit. See Table 3 for the application of this model to three different transportation systems.

Table 3. Applications of the transportation model elements.

Model Element	Road	Railroad	Natural gas Pipelines
Backbone	Wearing surface Sub-grade Parking Lots Curbs	Rails, ties, ballast Switchyards Terminals Stations	Pipes Compressor stations
Carrier	Automobiles Motorcycles Trucks Busses Horse & buggy	Locomotives Cargo cars Passenger cars	Pressure (note that generalized models sometimes require creative application)
Commodity	People Food Manufactured goods	People Coal Grain Wood	Natural gas
Control	Signage Lights Police Red light cameras	Lights Grade crossings Automatic train controls	Pressure regulators Flow meters

This model was created for the specific purpose of helping students see the similarities and differences in the five transportation sectors listed by DHS: roads, railroads, water, air, and pipelines. It supplements but does not replace other transportation models like Greenshield's flow model, the gravity model, or the logit model.

6.1.2 Sustainability models

While some aspects of *sustainability*[*] are inherent in the models presented, the authors have not yet developed a specific sustainability model. Other organizations have recognized the need for advancing sustainable development and have developed approaches to promote sustainable design. One common approach is to create a “rating tool” consisting of numerous credits for which a project can earn points within specific catego-categories. As design teams consider each credit and try to earn points for their project, they must apply critical thought as to how their project will perform and meet the needs of society, both today and in the future. Whether a project earns a “platinum” rating or does not even achieve certification, the design team has at least thought about the project more completely in terms of sustainability than it might have otherwise. As one organization puts it, the purpose of their rating tool is to “initiate a systemic change… to transform the way infrastructure is designed, built, and operated” (ISI 2012). Another organization states that their goal is “market transformation – to fundamentally change how we design, build, and operate buildings and communities” (USGBC 2011).

There are many sustainable development rating systems in existence (see Table 4). The authors do not support any one rating tool over the other. However, it is important to understand the usefulness of these rating tools when it comes to applying the infrastructure models presented in this report. Especially when it comes to developing infrastructure, integrated project teams should consider if any existing rating tool might be of value. By considering the topics of concern within one or more of these rating systems, project teams can think more critically and completely about their projects. Nevertheless, it is the collective opinion of the authors that these rating tools are not fully scalable and/or global in scope. Thus, it would be helpful to develop a conceptual model for sustainability that nests with the other models presented in this report and help us to *understand, visualize, and describe* sustainability at both the project and program levels.

[*] The most commonly accepted definition of sustainable development comes from the 1987 United Nations’ World Commission on Environment and Development (Brundtland Commission). The Brundtland Commission defined sustainable development as “development which meets the needs of current generations without compromising the ability of future generations to meet their own needs” (Brundtland Commission 1987)..

Table 4. Non-exhaustive list of sustainability rating tools in use in the United States.

Rating System or Guide	Primary Focus	Proponent
BE^{2}ST-in-Highways	▪ Assists state-level departments of transportation in using recycled materials and industrial byproducts in transportation infrastructure	▪ Recycled Materials Resource Center
Build it Green	▪ Residential homes	▪ Build it Green (nonprofit organization in California)
Energy Star	▪ Products/appliances ▪ New homes ▪ Commercial buildings ▪ Industrial plants	▪ U.S. Environmental Protection Agency
Envision	▪ All types of Civil Works projects (except buildings and facilities): roads, bridges, pipelines, railways, airports, dams, levees, landfills, water treatment systems, etc.	▪ Institute for Sustainable Infrastructure (ISI)
Green Globes	*Multiple rating tools for buildings:* ▪ New buildings or significant renovations ▪ Management and operations of existing buildings ▪ Building emergency management ▪ Building intelligence	▪ Green Building Initiative (USA version)
GreenLITES	▪ Transportation infrastructure	▪ New York State Department of Transportation
Greenroads	▪ Roadway and bridge projects	▪ Greenroads Foundation
I-LAST	▪ State highway projects	▪ State of Illinois
ICC 700 National Green Building Standard	▪ Residential homes ▪ Multifamily buildings ▪ Remodeling or additions ▪ Hotels ▪ Dormitories ▪ Residential land improvements	▪ International Code Council, ▪ National Association of Home Builders
Infrastructure Voluntary Evaluation Sustainability Tool (INVEST)	▪ Transportation services	▪ Federal Highway Administration

Rating System or Guide	Primary Focus	Proponent
International Green Construction Code	▪ Buildings	▪ International Code Council ▪ American Institute of Architects ▪ ASTM International ▪ ASHRAE ▪ U.S. Green Building Council (USGBC) ▪ Illuminating Engineering Society
Leadership in Energy & Environmental Design (LEED)	*Multiple rating tools for buildings (and neighborhoods):* ▪ New construction and major renovations ▪ Core and shell ▪ Schools ▪ Healthcare ▪ Retail ▪ Commercial interiors ▪ Retail interiors ▪ Existing buildings: operations & maintenance ▪ Homes ▪ Neighborhood development	▪ U.S. Green Building Council
Living Building Challenge	▪ Renovation ▪ Landscape or infrastructure ▪ Buildings ▪ Neighborhoods	▪ Cascadia Green Building Council

6.1.3 Your model for your problem

These models are useful to the degree that they help us to understand and solve problems. Other models will be necessary to solve other problems, and these models will certainly evolve when used in specific applications. Commanders and planners who produce models based on this work are encouraged to share them with the authors and ERDC-CERL for inclusion in follow-on work. Furthermore, commanders and planners who develop suggested improvements for the models outlined in this report are highly encouraged to share them with the authors and ERDC-CERL.

7 Implementing and Applying the Models

There are many models—like OCOKA* for the military aspects of terrain and METT-TC† for the mission variables—that are in use by the Army today. The originators of these models developed them through study and taught them in military schools. They continue to be used, not because they are part of the military education system, but because they work. We developed the models in this paper in the belief that they will be useful. To validate this, they must be taught and then used. Since 2010, we have been involved in a deliberate educational program to provide these models vertically and horizontally through the professional military education system.

7.1 CE350: Infrastructure Engineering

CE350 is a junior-level course taught at West Point by the Department of Civil and Mechanical Engineering. The course is taken each year by about 50 civil engineering majors and 70 three-course engineering sequence cadets.‡ The course is built around the Infrastructure Component Model and includes introductions to the Assessment and Infrastructure Resilience Models. Major blocks of instruction include network theory and application; water, wastewater, and trash; electricity; transportation; and military applications of infrastructure. Since 2011, about 120 cadets have graduated each year having been taught this class. The graduates are commissioned in different branches of the Army and subsequently provide an infusion of these models and concepts within the broader Army (assuming, of course, that they retain, recall, and apply the knowledge they learned in class).

* Observation and Fields of Fire, Cover and Concealment, Obstacles (man-made and natural), Key or Decisive Terrain, Avenues of Approach.

† A mnemonic used by the United States Military to help commanders remember and prioritize what to analyze during the planning phase of any operation. It stands for Mission, Enemy, Terrain, Troops available, Time, and Civilian considerations.

‡ At West Point, students who do not major in engineering are required to take a three course engineering sequence in one of the engineering disciplines. The civil engineering three-course sequence consists of CE300 Statics and Mechanics of Materials, CE350 Infrastructure Engineering, and CE450 Base Camp Planning and Construction Management.

7.2 CE490: Designing Resilient Infrastructures

CE490 is a senior-level elective course taught at West Point by the Department of Civil and Mechanical Engineering to both civil engineering majors and selected cadets from the three-course engineering sequence. Using the Infrastructure Resilience Model as a framework, the course presents blocks of instruction on national strategy and policy, risk management, blast effects modeling, protective and resilient design strategies, and military applications. Since 2009, about 20 cadets, commissioned in various branches, have graduate each year having taken this course. It is known that at least one graduate from this course used course concepts during a deployment (Vail 2011).

7.3 JEOC: Joint Engineer Operations Course

The Joint Engineer Operations Course (JEOC) teaches students to understanding sister service engineer capabilities and considerations for joint engineer staff and prepares engineers for future joint deployments, staff assignments, and homeland operations. It also prepares engineers from all military services for assignment to a Joint Task Force. The course focuses on joint engineer doctrine, service engineer capabilities, and how to use service engineer capabilities in support of joint and service engineer requirements. The JEOC meets four or five times a year with 30–60 officers and senior noncommissioned officers in attendance. Since 2012, the infrastructure models have been presented as a one-hour seminar during the course. The presentation is done by various distance education mechanisms including video teleconference (VTC), Defense Connect Online (DCO), or telephone conference. Participants typically rate the seminar highly in the course-end feedback, and there have been multiple requests for distribution of supplementary materials.

7.4 ECCC: Engineer Captains Career Course

The Engineer Captains Career Course (ECCC) is a 23-week course to prepare Army captains for service as battalion and brigade staff officers and company commanders. The course includes sections on administration, leadership foundations, doctrine, engineer tactical tools and explosive hazards, engineer planning, battle-focused training, general engineering, capstone warfighter exercise with military police and chemical officers, and command fundamentals (U.S. Army n.d.). Since 2012, the Infrastructure Component Model and Infrastructure Assessment Model have been presented in a 4-hr seminar with practical exercises given to each ECCC small group at an instructor-to-student ratio of 1:32. The seminar falls at the end of the general engineering block of instruction and just prior to the capstone block of instruction. The students consistently rate the seminar as one of the highlights of the ECCC.

8 Conclusions

From corporal to general, Army leaders care about a great many skills because they use them directly. Skills in gunnery and vehicle operation allow them to close distance and destroy the enemy through fire and movement. Skill in the application of communications equipment allows them to call for fire support, air support, and resupply. Skill in maintenance ensures maximum combat power is available, while skill in medicine ensures soldier remain healthy and are healed from injury. Is short, Army leaders care about many skills because they use them directly to accomplish assigned missions and return home safely.

If directly asked, “Do you care about infrastructure?” most commanders and staffs will respond, “No, of course not.” With most having never been taught how to understand the infrastructure or its relationship to mission accomplishment, this is a perfectly understandable response. The truth is, these leaders need to be taught to care about infrastructure—not because they want to deal with it (as is the case with gunnery, maintenance, medicine, fires, and other Army skills)—but because they DO NOT want to deal with it. Ignorance of the importance and function of the infrastructure leads to poor targeting decisions which, while supporting initial tactical requirements, result in extensive problems and extreme costs when the fighting is over and we set about to restore a functioning, civil society. Further, good infrastructure decisions made in a post-conflict environment advanced the overall stability objectives, while poor decisions offer no advancement at best, or actually decrease stability at worst, and prolong the deployment. If Army leaders do not deal correctly with the infrastructure the first time, they will continue to deal with it again and again and again until they either get it right or just quit and go home.

This ERDC technical report provides a researched, proven, cognitive framework for understanding, visualizing, and describing infrastructure under any condition to any audience. This cognitive architecture will allow commanders, leaders, planners, managers, and citizens to think critically, creatively, and completely about infrastructure problems; identify and engage with all stakeholders; and formulate and implement solutions that are technically, socially, environmentally, economically, and politically viable. This report also details the scholarship and development behind these models, the educational programs used to teach the models, and examples of the application of the models. A critical mass of officers who have been taught to think about infrastructure in these terms is now in the Army. After they have had the opportunity to use these models to solve actual problems under uncontrolled conditions, the authors hope they will contribute to the advancement of this work by validating, modifying, or transforming the models to meet emerging challenges.

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Appendix A: History of Infrastructure in Army Doctrine

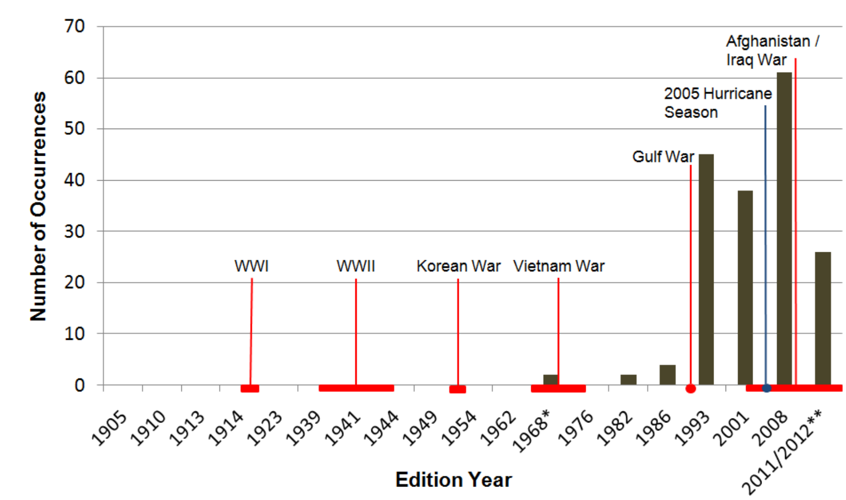
Military doctrine reflects the fundamental set of principles that guides forces in achieving national security objectives. The Army uses a capstone operational doctrine that is currently on its 19th edition. First published in 1905 as "Field Service Regulations," this doctrine was later renamed Field Manual (FM) 100-5: "Operations" in 1939, and in 2001, it was redesignated as FM 3-0: "Operations." Today, the Army capstone operational doctrine is contained in Army Doctrinal Publication (ADP) 3-0 and Army Doctrine Reference Publication (ADRP) 3-0, both titled "Unified Land Operations." The authors have traced the term "infrastructure" through the Army's historical capstone operational doctrine to provide a picture of the evolution of infrastructure's importance in successfully accomplishing national security objectives and concluding conflict; the result is shown in Figure 35. Historically, the Army has had three distinct views on infrastructure:

- first, infrastructure was something required for logistics to get personnel and materiel to the fight;
- second, infrastructure was an opportunity to target enemy capabilities; and
- third, infrastructure became something vital to protect, rebuild, and develop to successfully conclude military operations.

Army doctrine first recognized "infrastructure" as a resource for Combat Service Support personnel to deploy, build up, and project forces in a conflict. In the 1982 edition of FM 100-5: "Operations," military planners were advised to consider if a battlefield would be "sophisticated" or "unsophisticated" with regards to "existing infrastructure of communications, air defense, logistic facilities, and ports" (U.S. Army 1982). This theme continued in the 1986 edition which discussed "theater infrastructure" such as "ports, airfields, depots, repair facilities, supplies, and transportation facilities" that are required to deploy and build up forces during a conflict (U.S. Army 1986).

The year 1993 marked a drastic increase in the appearance of infrastructure in capstone doctrine, noting that "ports, roads, and other assets will affect the sequencing of units and tempo of entry operations” (U.S. Army 1993). The Army learned to rely on infrastructure that was not its own to get its forces to the fight after experiences in Desert Shield and Desert Storm where over 5 months was spent using ports, airfields, roads, and installations to build up forces in the Middle East for a ground campaign that lasted only 100 hr. Though prominent in the 1993 manual, the word “infrastructure” was solely focused on “deployment infrastructure,” referring to those civil works projects helpful in deploying and projecting military forces. From this perspective, infrastructure was viewed only as an asset to be used like a commodity.

Figure 35. Number of occurrences of the term “infrastructure” in the U.S. Army’s capstone operational doctrine manuals.



* The term "infrastructure" appears twice in the 1968 edition of FM 100-5: *Operations*. However, its usage is not consistent with current terminology. In 1968, the term referred to the structure of organizations as opposed to facilities, services, or installations.

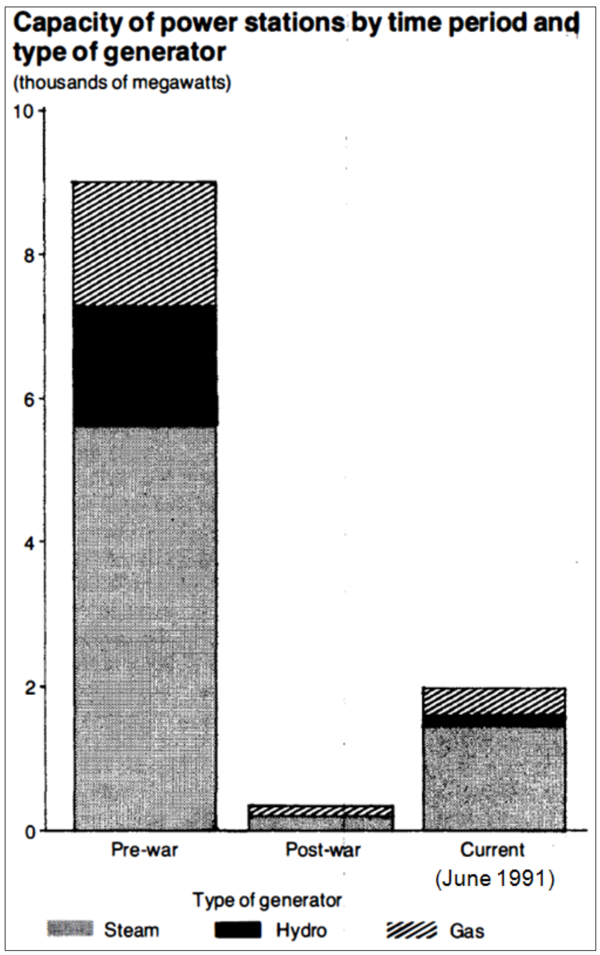
** *Unified Land Operations* is both ADP 3-0 (2011) and ADRP 3-0 (2012); thus, the number of occurrences of the term "infrastructure" in each have been combined.

Near simultaneously, a second point of view that categorized infrastructure as a target was developing in doctrine. This view saw infrastructure as a target of opportunity to exert U.S. will upon the enemy. The 1986 edition of FM 100-5: “Operations” described how the Army would fight under the concept of “AirLand Battle” (U.S. Army 1986). Previously, the Air Force expended copious amounts of ammunition to guarantee hits against its targets. However, the invention of smart weapons revolutionized air power. The Air Force and Army would now use close coordination to defeat the enemy. Army units would engage ground elements while the Air Force used smart weapons to target roads, bridges, ports, and forces not yet in contact, thus simultaneously attacking the enemy in depth. To facilitate this deep attack, the 1986 edition recommended that enemy infrastructure supporting air operations be neutralized or destroyed to gain control of the air environment (U.S. Army 1986). From this perspective, infrastructure is a target to be attacked.

The 1993 edition similarly continued the perspective of infrastructure as a target. It described “four major physical elements of the environment of operations” which are “geography, terrain, weather, and infrastructure” (U.S. Army 1993). This edition gave the first doctrinal definition of the term infrastructure, although two different definitions were given in the same document. Within the text, infrastructure was defined as consisting “of the facilities, equipment, and framework needed for the functioning of a system, city, or region.” (ibid.). However, in the glossary, infrastructure was defined as “all fixed and permanent installations, fabrications, or facilities for the support or control of military forces” (ibid.). Army doctrine began to view infrastructure in terms of the services essential for the functioning of society, yet it retained a glossary definition supporting its first perspective regarding military logistics. Of significant interest in this 1993 edition is the concept of “strategic attack.” “Strategic attacks are carried out against an enemy’s center of gravity, which may include national command elements, war production assets, and supporting infrastructure (for example, energy, transportation, and communications assets)” (ibid.). The perspective, again, is of infrastructure being a target that should be exploited.

This view of infrastructure as an enemy resource was in the minds of military planners who selected air targets during the First Gulf War in 1991. The 43-day air bombardment of Iraq followed the construct of “strategic attack” and sought to disable society itself. Targets were broken down into 12 different categories, six of which were sectors of infrastructure: communications, airfields, railroads and bridges, oil, electricity, and naval ports. Planners specifically selected targets that the Iraqis were unable to repair without foreign assistance. One Air Force planner was quoted in the Washington Post as saying, “Big picture, we wanted to let people know, ‘Get rid of this guy and we'll be more than happy to assist in rebuilding. We’re not going to tolerate Saddam Hussein or his regime. Fix that, and we'll fix your electricity’” (Gellman 1991). The allies flew 215 sorties against electrical plants alone. U.S. analysts estimated it would take about a year to repair the switchyards and transformer substations – with U.S. assistance. The United States also targeted Iraq's 20 power generation stations which had an estimated collective repair time of 5 yr. After a week of aerial bombardment, the Iraqis were forced to shut down what remained of their power grid. A team of Harvard medical professionals conducting a public health assessment in the spring of 1991 found that 17 of Iraq's 20 power generation plants were either damaged or destroyed, 11 of which were total losses (Harvard 1991). Figure 36 presents an assessment of Iraq's generating capacity from pre-war to June 1991.

Figure 36: Assessment of Iraqi power plants in June 1991 (Harvard 1991, 21).



These attacks against Iraqi infrastructure were meant to give the United States "leverage." Military planners knew that Saddam Hussein could not restore his own electricity. They thought one of two outcomes would happen: (1) either the people would rise up against their leader and oust Saddam Hussein themselves, or (2) Saddam himself would agree to United Nations (UN) conditions to receive help to restore electricity. Unfortunately, neither outcome happened. Instead, the lack of electrical power stopped water purification and sewage treatment across the country. Raw sewage backed up in the streets where children played, and wastewater treatment facilities discharged raw sewage directly into the rivers, polluting drinking water sources downstream. The effect was epidemic levels of cholera and typhoid. The team of Harvard medical providers estimated that “at least 170,000 children under five years of age will die in the coming year from the delayed effects” of the bombing (Harvard 1991). Additionally, a change in the political climate and administration in the United States resulted in no strategic desire to continue pushing on this political lever.

The next edition of the Army’s capstone operational doctrine was the 2001 edition, FM 3-0: “Operations.” This edition revealed some obvious changes after previously considering infrastructure as a target. The doctrine stated that commanders should, “consider the effects of destroying the economic infrastructure” and that “Army forces must simultaneously defeat an adversary while protecting noncombatants and the infrastructure on which they depend” (U.S. Army 2001). The doctrine specifically said that engineer units must “rebuild” infrastructure, which insinuated that repair of infrastructure that was once operational yet rendered ineffective by the United States would be repaired by the United States (U.S. Army 2001). Additionally, this manual (published four months prior to the 9/11 attacks) described how the Army could provide domestic support operations and help protect homeland infrastructure.

In 2008, the Army published a new edition of FM 3-0: “Operations,” which provided a doctrine of protecting, rebuilding, and developing infrastructure as a critical part of conducting “Full Spectrum” military operations. Infrastructure remained a variable of the operational environment, now abbreviated by the acronym PMESII-PT. Infrastructure received a new doctrinal definition as comprising “the basic facilities, services, and installations needed for a society to function.” The concept of “Landpower” was defined, which included the ability to “restore infrastructure and reestablish basic civil services” (as referred to in Section 2.5 of this report). As a part of Full Spectrum Operations, there are four elements – offense, defense, stability, and civil support – that require simultaneous effort. Each element has specified tasks and purposes. One purpose of Defensive Operations is to “protect the populace, critical assets, and infrastructure.” A primary task of Stability Operations is to give “support to economic and infrastructure development.” Additionally, two purposes of Civil Support

Operations are to “restore essential services” and “protect infrastructure and property” (U.S. Army 2008).

The 2008 edition illustrated lessons learned in Iraq and Afghanistan, as well as lessons learned at home due to the 2005 hurricane season with Hurricanes Katrina, Wilma, and Rita. Infrastructure no longer simply referred to the ports, rails, and roads used to project military might. More importantly, infrastructure was no longer a primary target under “strategic attack.” After years of fighting in Iraq and Afghanistan, we learned that infrastructure is something we must protect, rebuild, and develop if we want to end conflict and hand over security operations to a functioning government capable of providing basic services to its society. These lessons were further emphasized by the devastating hurricanes that struck the United States in 2005. Damage to infrastructure had widespread and devastating impacts upon society. Our perspective on infrastructure significantly changed.

Today, this concept of infrastructure’s importance in military operations lives on in the new ADP and ADRP 3-0: “Unified Land Operations.” Unified Land Operations means to “seize, retain, and exploit the initiative to gain and maintain a position of relative advantage in sustained land operations in order to create the conditions for favorable conflict resolution” (U.S. Army 2012). It is executed through Decisive Action by means of two Army Core Competencies and guided by Mission Command. The two Core Competencies are Combined Arms Maneuver and Wide Area Security. Wide Area Security is defined as “application of the elements of combat power in unified action to protect populations, forces, infrastructure, and activities; to deny the enemy positions of advantage; and to consolidate gains in order to retain the initiative” (ibid.). Clearly, the Army’s view of infrastructure has evolved through the years from single or disparate perspectives to one where infrastructure is an asset to support deployments and sustainment, a target to be attacked for an effect, *and* an asset to be protected, restored, and developed in support of stability and broader strategic objectives. Experiences have shown that all of these perspectives must be considered simultaneously for accomplishment of the mission. (Refer again to Figure 11 in Section 2.4.)

Appendix B: Evolution of the Infrastructure Component Model

The presence of the models in this report may give the appearance that they spring fully formed from the minds of the authors. This is not the case. These models have evolved into their current forms as a result of multiple semesters of teaching, multiple papers, and multiple knock-down drag-out arguments. This appendix demonstrates part of this evolution by showing three key evolutionary stages of the Infrastructure Component Model.

When first taught in 2010, the Infrastructure Component Model consisted of these eight elements that used big words.

- *Production*—extracting, generating, or procuring the raw desired product
- *Processing*—converting the raw product into a usable and transmittable form
- *Transmission*—movement of product from point of processing to area of consumption
- *Distribution*—connection high volume transmission systems with low volume customers
- *Consumption*—use of the desired product by the person or organization paying for it
- *By-product disposal*—removal and disposal of waste
- *Regulation*—both the societal regulatory environment and the required SCADA systems
- *Financing*—a means of customers paying for services and owners paying for systems

After being refined through three terms of teaching, the model became made up of the following five elements.

- *Generation*—combining the Production and Processing elements.
- *Bulk Transmission*—same as above definition with the addition of “bulk” to indicate the movement of large quantities.
- *Distribution*—same as above
- *Use*—same as above, but with a simpler word

- *Discard/Recycle*—same as above, but with a simpler word

The goal of this refinement was to reduce the model to the minimum elements that were both necessary and sufficient for the functioning of an infrastructure. Additionally, the goal was also to make the model memorable, and most people only recall lists of about five items.

In the spring of 2012 when we began the process of formalizing the models and the supporting scholarship, we revisited the elements to ensure they were meeting the goals of necessary and sufficient and memorable. Based on those discussions,* the fifth function became *Waste Management* which included ignoring, disposing, recycling, repurposing, and reusing the waste. We felt these five functions met the necessary and sufficient test for making an infrastructure function for a single day. They do not, however, ensure the long-term functioning of the infrastructure. For this, the element of *coordination* was returned to the model, encompassing the aspects of regulation and finance in the original formulation while using the simpler words in the second formulation. The result is there are now six elements in the Infrastructure Component Model which is fully explained in Section 4.3.

* OK, if you read this far into the report, you should be rewarded with a bit of humor and the truth; the discussions were really knock-down, drag out Texas Cage Death Matches, with elbows thrown and people coming off the top ropes. Well, maybe they were not that bad. Yeah, they really were, but it was all from our desire to get the models RIGHT. Since we intended the models to change the way the Army thinks about infrastructure, we felt the burden that getting them RIGHT imposed, and thus we were willing to come to (verbal) blows to get the models RIGHT. Well, maybe there were some physical blows, but none of them left any permanent marks (we think).

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14. ABSTRACT

The Army's understanding of infrastructure as an operational variable has been evolving over the past 30 years in response to significant events ranging from international conflicts to domestic weather-related disasters. These experiences have combined to drive a significant shift in infrastructure doctrine, which now demands that commanders and staffs understand, visualize, and describe the infrastructure variable to accomplish the Army's assigned infrastructure missions of protecting, restoring, and developing infrastructure—all missions essential to restoring stability after conflict or disaster. Current Army doctrine, however, does not say how commanders and staffs are to approach these challenging tasks. This report presents a cognitive framework for understanding, visualizing, and describing infrastructure by using five conceptual models created to allow commanders and staffs to think critically, creatively, and completely about infrastructure problems. The report also includes the scholarship behind the models including verification, validation, and certification as well as example applications of the models to actual situations. Infrastructure is a concern for both civil society and the military, and the models work equally well in both. The authors actively solicit feedback from any reader on the use, application, and improvement of these models.

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