COMMENTARY

EDUCATING THE INFRASTRUCTURE PROFESSIONAL
A New Curriculum for a New Discipline

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The United States has the most extensive, complex, and arguably the most sophisticated system of public infrastructure in the world. This linked system of facilities and activities provides the broad range of essential services that support our economic well-being and overall quality of life. In light of the critical role that infrastructure plays in our everyday lives and the many challenges facing the owners and operators of these systems, professionals of the highest caliber are needed to support and manage the nation's infrastructure. This article suggests that existing university curricula at the undergraduate and graduate levels are generally inadequate to provide the necessary integrated and cross-disciplinary training required for infrastructure professionals. A focused activity should be undertaken to assess the educational needs and the adequacy of the training of those professionals and propose necessary curricula improvements.

As the nation with the most extensive, complex, and arguably the most sophisticated system of public infrastructure in the world, the United States exhibits strangely mixed feelings toward these systems. Despite a demand for high quality services, support for the individual projects that provide these services is often lukewarm or lacking. Not altogether surprising, a recent survey indicated that a rather small percentage of the American public actually knows the answer to such basic questions as where their water and electricity come from and how their liquid and solid waste is disposed of. At the same time, there are almost continuous warnings sounded by the public works and engineering communities that these systems are crumbling beneath our feet and desperately in need of huge cash outlays to make them whole. A presidential commission recently found significant portions of our critical infrastructures to be at risk (The President's Commission on Critical Infrastructure Protection [PCCIP], 1997) and an executive order has been issued to address the protection of these critical systems. At the same time, Not in My Backyard (NIMBY) and related phenomena provide one window to how many Americans view the physical manifestations of these vital systems. Large projects are particularly suspect as evidenced by the current cynicism directed toward Boston's Central Artery project and the proposed replacement for the Woodrow Wilson Bridge that spans the Potomac River just south of Washington, D.C. Sensitivity to these issues has progressed to the point that when

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funding for the bridge replacement was announced by President Clinton and Secretary of Transportation Rodney Slater in 1998, they felt compelled to assure listeners that the project was really needed and not merely part of the local pork barrel. That such assurances were even thought necessary for a 40-year-old bridge of questionable structural integrity that carries almost 200,000 vehicles a day around the nation's capital is a telling comment. If this climate of suspicion and cynicism coupled with ignorance and indifference is going to be changed, a community of trained infrastructure professionals needs to play an active role in education, outreach, and the professional practice of infrastructure management.

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The Nature of Infrastructure

For the purposes of this article, the term *infrastructure* is defined as the linked system of facilities and activities that provides the services generally necessary to support our economic well-being and overall quality of life. Any discussion of infrastructure must be cognizant of this duality of facilities and services. Although it may be the hardware (i.e., the highways, pipes, and plants) that captures our attention, it is actually the services that these systems provide that is of real value to the public.

In practice, these systems have many functions and must address multiple objectives. They have multiple stakeholders who use, benefit from, or are otherwise impacted by them. Their complexity from a technical, financial, and sociopolitical standpoint requires multidisciplinary skills in planning, operation, and evaluation.

Multiple Objectives

Understanding infrastructure requires an awareness that it addresses multiple and often competing objectives simultaneously. For example, the primary objective in the movement toward regulated municipal water supplies in the last century was to improve public health through the elimination of water-borne diseases. However, once in place, adequate supplies of clean water made communities more attractive to businesses and industries concerned with fire protection as well as suitable water for manufacturing and processing. In turn, this led to increased prosperity through economic growth and development. Similarly, waste water treatment facilities provide enhanced water quality in the receiving bodies as their primary objective, but can also offer the benefits of improved recreation and other environmental amenities.

Infrastructure is primarily the physical means of providing services. The needs for these services and the technologies for providing them will change over time, as will the value society places on them. Thus, infrastructure professionals will need to understand the multiple roles infrastructure plays in modern society as well as the multiple ways of providing those services.

Infrastructure Stakeholders

The stakeholders for public infrastructure represent a broad cross-section of government, community, and professional groups. These stakeholders have traditionally included elected officials, public administrators, citizens and neighbors, the financial community, engineers, architects, and planners. With the increasing dependence of the military on civilian infrastructures, the U.S. defense establishment can also be added to the list of interested stakeholders. As the political groupings grow broader—from the local to the regional, state, and national levels—the list of issues also grows and requires the balancing of multiple and often competing objectives. Figure 1 illustrates the diverse communities of interest that infrastructure serves. Managers with a broad holistic perspective will be needed to integrate these physical systems and the services that they provide. These managers will have to promote and structure

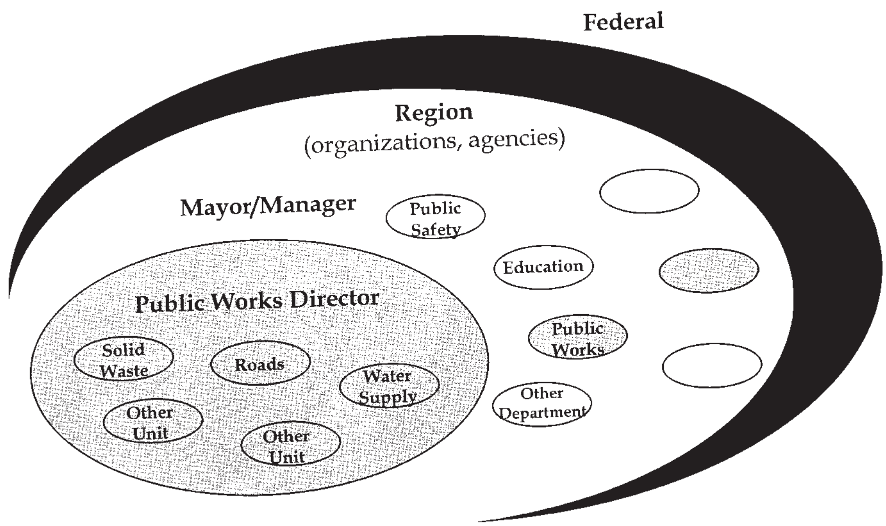

Figure 1: Infrastructure Has Stakeholders at All Organizational Levels
SOURCE: National Research Council (1995b).

interactions among stakeholders to be able to articulate community objectives and the role of infrastructure in realizing them.

The Multidisciplinary Nature of Infrastructure

Modern infrastructure is a complex technological system whose effective operation and management need to draw from a broad range of disciplines. Infrastructure managers are routinely called on to synthesize a vast array of information from fields as diverse as civil engineering, materials science, government operations, economics and finance, social and political science, and natural ecology. Traditionally trained civil engineers usually are equipped to deal with the technical side of public works issues but they typically lack the breadth to apply that technical knowledge effectively in complex public settings. Viable and cost-effective engineering alternatives are thus often abandoned because public concerns were addressed insensitively or not at all. Public administrators, on the other hand, do not usually have the background to assess and implement technical solutions to public needs.

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The rise of the environmental review process increased the requirements for stakeholder involvement and consideration of multiple objectives beyond the technical and financial in the evaluation framework. However, the technical aspects of infrastructure are no less important—projects must still work when the switch is thrown. Desired services must be delivered reliably and at reasonable cost, and the evaluation of full costs and benefits must account for them. Even if we have not yet developed the tools to measure and quantify all factors directly, this increased awareness has at least ensured that they be considered. This reasonably leads to the question of the proper training for the infrastructure professional, whose job it is to provide needed services and spend public funds appropriately.

Some Selected Infrastructure Issues

The American Society of Civil Engineers (ASCE) recently released a “Report Card for America’s Infrastructure” that assigned a letter grade to 10 categories of public works and

ASCE
American Society of Civil Engineers

1998 Report Card for America's Infrastructure

Subject	Grade	Comments
Roads	D-	More than half (59 percent) of our roadways are in poor, mediocre or fair condition. More than 70 percent of peak-hour traffic occurs in congested conditions. It will cost $263 billion to eliminate the backlog of needs and maintain repair levels. Another $94 billion is needed for modest improvement -- a $357 billion total.
Bridges	C-	Nearly one of every three bridges (31.4 percent) is rated structurally deficient or functionally obsolete. It will require $80 billion to eliminate the current backlog of bridge deficiencies and maintain repair levels.
Mass Transit	C	Twenty percent of buses, 23 percent of rail vehicles, and 38 percent of rural and specialized vehicles are in deficient condition. Twenty-one percent of rail track requires improvement. Forty-eight percent of rail maintenance buildings, 65 percent of rail yards and 46 percent of signals and communication equipment are in fair or poor condition. The investment needed to maintain conditions is $39 billion. It would take up to $72 billion to improve conditions.
Aviation	C-	There are 22 airports that are seriously congested. Passenger enplanements are expected to climb 3.9 percent annually to 827.1 million in 2008. At current capacity, this growth will lead to gridlock by 2004 or 2005. Estimates for capital investment needs range from $40-60 billion in the next five years to meet design requirements and expand capacity to meet demand.
Schools	F	One-third of all schools need extensive repair or replacement. Nearly 60 percent of schools have at least one major building problem, and more than half have inadequate environmental conditions. Forty-six percent lack basic wiring to support computer systems. It will cost about $112 billion to repair, renovate and modernize our schools. Another $60 billion in new construction is needed to accommodate the 3 million new students expected in the next decade.
Drinking Water	D	More than 16,000 community water systems (29 percent) did not comply with the Safe Drinking Water Act standards in 1993. The total infrastructure need remains large -- $138.4 billion. More than $76.8 billion of that is needed right now to protect public health.
Wastewater	D+	Today, 60 percent of our rivers and lakes are fishable and swimmable. There remain an estimated 300,000 to 400,000 contaminated groundwater sites. America needs to invest roughly $140 billion over the next 20 years in its wastewater treatment systems. An additional 2,000 plants may be necessary by the year 2016.
Dams	D	There are 2,100 regulated dams that are considered unsafe. Every state has at least one high-hazard dam, which upon failure would cause significant loss of life and property. There were more than 200 documented dam failures across the nation in the past few years. It would cost about $1 billion to rehabilitate documented unsafe dams.
Solid Waste	C-	Total non-hazardous municipal solid waste will increase from 208 to 218 million tons annually by the year 2000, even though the per capita waste generation rate will decrease from 1,606 to 1,570 pounds per person per year. Total expenditures for managing non-hazardous municipal solid waste in 1991 were $18 billion and are expected to reach $75 billion by the year 2000.
Hazardous Waste	D-	More than 530 million tons of municipal and industrial hazardous waste is generated in the U.S. each year. Since 1980, only 423 (32 percent) of the 1,200 Superfund sites on the National Priorities List have been cleaned up. The NPL is expected to grow to 2,000 in the next several years. The price tag for Superfund and related clean up programs is an estimated $750 billion and could rise to $1 trillion over the next 30 years.

America's Infrastructure G.P.A. = D
Total Investment Needs = $1.3 Trillion
(estimated five-year need)

A = Exceptional
B = Good
C = Mediocre
D = Poor
F = Inadequate

Each category was evaluated on the basis of condition and performance, capacity vs. need, and funding vs. need.

American Society of Civil Engineers, Washington Office, 1015 15th Street, NW, Suite 600, Washington, DC 20005; 202/789-2200

Figure 2: Report Card for America's Infrastructure
SOURCE: American Society of Civil Engineers (1998).

Although the public will generally support efforts to improve infrastructure systems if a defensible case for doing so is presented, infrastructure is incredibly elastic. One of the reasons that the public has probably not raised a great hue and cry over the state of the infrastructure may be that it keeps functioning at an acceptable level over a broad range of conditions.

services (see Figure 2). The letter grades were determined by a panel of engineers who evaluated each category on the basis of its condition and performance, need versus capacity, and need versus funding. The primary outcome of the assessment was that, overall, the nation's infrastructure is considered to be in poor condition. This effort revisited a concept first advanced by the National Council on Public Works Improvement in 1988; recalling that effort, the ASCE report stated that "the overall condition of our infrastructure has not improved in the past ten years and in some categories has worsened." The panel performing the assessment also estimated that the investment needs over the next 5 years total $1.3 trillion.

The debate over the condition of the nation's infrastructure has been recurring for over 20 years and there is no question that during the next several decades there will be a need to renew or replace a significant percentage of the country's public architecture as well as its transportation, communications, environmental, and power system infrastructures. However, the actual magnitude of that task, and its cost, remains elusive. Although the recent ASCE effort was useful for again focusing attention on what is a serious national concern, it does not provide a basis for setting investment priorities or for assessing the effectiveness of infrastructure investment. Basing need solely on the physical condition or age of an infrastructure system without linking

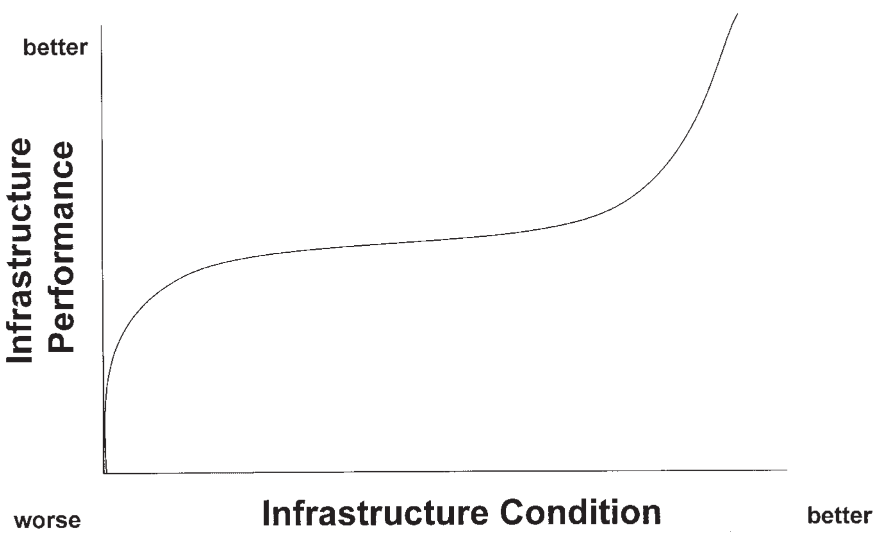

Figure 3: Infrastructure Performance Is Noticeably Affected by the Condition of the System Only at the Extremes

it to system performance will generally overestimate investment requirements—particularly in the case of older, larger systems. Although the public will generally support efforts to improve infrastructure systems if a defensible case for doing so is presented, infrastructure is incredibly elastic. One of the reasons that the public has probably not raised a great hue and cry over the state of the infrastructure may be that it keeps functioning at an acceptable level over a broad range of conditions. Figure 3 depicts this scenario wherein performance is noticeably affected only at the extremes of system condition. Well-maintained infrastructures can appear to be an expensive luxury when marginally maintained systems provide essentially the same level of service. Unfortunately, by the time service delivery is affected to the point where it is noticed by its customers, the cost to restore service to acceptable levels can be exorbitant.

Advances in technologies such as condition assessment and life-cycle analysis, decision sciences, and information management (as well as the basic science of materials performance and deterioration) all offer the opportunity to fundamentally improve infrastructure systems. However, it is a frequently voiced opinion within the infrastructure community that innovative deployment of new technologies and methods for infrastructure applications lag far behind the pace at which research is advancing the knowledge base. This inability to match technological capabilities to infrastructure needs and to deploy these new technologies within communities is continually identified as a significant barrier to improvement of the built environment (Federal Facilities Council [FFC], 1996; New York University [NYU], 1997). However, successful management of these sociotechnological interfaces appears to be hampered by a shortage of professionals with the requisite interdisciplinary knowledge, training, and skills to identify and apply socially and politically acceptable technical solutions to community problems.

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In addition to the normal, everyday challenges faced by the infrastructure community, the 21st century promises to add extra concerns to that list. The end of the Cold War has dramatically changed the U.S. security picture, with far-reaching implications for public works and infrastructure. The increasing dependence of the defense establishment on such civil infrastructures as transportation, telecommunications, electric power, water supply, and emergency services makes them attractive targets for a range of potential adversaries. From a traditional security standpoint, these systems are essentially unprotected despite their importance (Little, Schroeder, McIntire, & Todd, 1998).

Possible threat scenarios include foreign and domestic terrorism, cyber-warfare, and the potential use of biological and chemical weapons. Overall, the opportunities for disrupting the nation and causing harm to our citizens are vast and the means for doing so are readily available to an alarming number of individuals and organizations. No less so than in earlier, perhaps more comprehensible times, this wide range of threats and targets requires that resource priorities be established for increased levels of assurance for critical national infrastructures.

The development of truly effective infrastructure assurance policies and programs will require coordination and collaboration between federal, state, and local governments. Competing factors (e.g., vulnerability vs. threat, security vs. openness, cost vs. risk) will have to be weighed and balanced—for not every infrastructure asset can be protected (or needs to be) with an equal level of security. Finally, the development and definition of cooperative government-industry relationships will also be critical to infrastructure protection efforts.

In the future, state and local governments and the private sector may have to develop infrastructure assurance policies, programs, and assessment methodologies to deal with threats to their infrastructure assets. In the face of these potential threats, infrastructure managers will be required to develop and deploy comprehensive strategies either to prevent attacks or, should they occur, to mitigate the damage, quickly recover services, and reconstitute lost infrastructure assets.

The Need for a New Educational Commitment

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Addressing these issues at the basic level of university preparation may provide a mechanism for making real advances in the modernization of our infrastructures and how we deal with them. Particular emphasis needs to be placed on the development of a workable paradigm for interdisciplinary thinking, communication, team building, and problem solving within the infrastructure community. Currently, where infrastructure has an identifiable role in the curriculum, it is usually on the engineering or operation of the hard, physical systems—not on the philosophy, theory, and practice of providing services. There are some very good university engineering programs in infrastructure. However, to a large degree, they deal with the traditional public works topics such as traffic operations, pavement management, water and sewerage systems, storm drainage, and general public works operations. None of them provides a focused curriculum aimed at producing a professional infrastructure practitioner. Although some of these programs are undoubtedly more on target than others, there does not appear to be a clear consensus among academics or, more important, between academia and practice on what comprises a desirable core competency for infrastructure professionals and how such a program should be structured. Outside of the engineering curricula, infrastructure and its operation and management is generally not addressed at all. The infrastructure community has apparently lost sight of the fact (or has at least not conveyed it particularly well) that many of the world's great architectural and engineering works were, at their core, infrastructure projects planned and executed by practitioners with budgets, schedules, clients, contractors, and critics. Indeed, much of the history of American development can be traced through the history of its infrastructure—of which many projects were initially economic failures (Monkkonen, 1995). The eventual success of many of these projects has since ratified the vision of their early proponents, if not their sense of timing.

A study conducted by the National Research Council (NRC) on the education of architects and engineers stressed the importance of teamwork, business, and communications skills and found them lacking overall in the engineering curriculum (NRC, 1995a). Regarding teamwork, the report noted that

> In graduate programs and advanced studio classes, there seems to be little opportunity for true teamwork. If there is teamwork, it exists informally among student peers. This does not help prepare the

> student for the multi-discipline teams encountered in institutions, architectural-engineering firms, government agencies, boards, and review commissions, or multi-disciplined design teams. (p. 52)

In the area of business skills,

> The committee concluded that most architectural and engineering students leave school with little knowledge of business, economics, and management and this adversely affects their ability to serve their clients, to understand the concerns of their employers, to manage projects effectively, to operate a design practice, and to qualify for more responsible positions. (p. 53)

The committee that prepared the report also agreed that good communication skills are vital to both engineers and architects and that the writing, speaking, and graphic communications skills of most graduates are poor. At the same time, the report noted that it may not be completely realistic to expect new graduates to function as professionals immediately upon graduation.

Conversations and correspondence with many notable engineering educators over the past few years have emphasized the difficulty of expanding the existing engineering curriculum. There is even an increased emphasis for condensed programs. In light of this, it may be necessary to establish a new degree discipline within colleges of engineering or structure a multidisciplinary degree program in a nonengineering department. This article does not suggest a solution. However, the issue is believed to be sufficiently critical to warrant focused discussion on curriculum. A proposed activity would be a forum for open discussion of the educational needs of infrastructure professionals and the adequacy of existing university curricula at the undergraduate and graduate levels for the training of those professionals. At a minimum, this activity should assess and attempt to build consensus for

1. The knowledge base necessary for engineers and other professionals to successfully manage complex infrastructure systems.
2. The basic curriculum elements and level of instruction necessary to develop a core competence, requisite to the desired knowledge base, that will produce better trained and more capable infrastructure professionals.
3. The means by which truly interdisciplinary thinking and communication skills can be developed and applied by a broad range of professionals to infrastructure problems.
4. The adequacy of available university-level programs.

Infrastructure is a serious business that is vital to our continued prosperity and quality of life. It is too important to be left to well-meaning but ill-prepared managers.

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