Engineering and Non-Engineering Aspects of Environmentally Sustainable Infrastructure

ASHRAF GHALY, Ph.D., P.E.
Professor of Engineering, Union College
Schenectady, NY 12308
ghalya@union.edu

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Abstract

Sustainable infrastructure entails many engineering and non-engineering aspects. The engineering features comprise design, construction, and operation. The non-engineering features involve economics, politics, and culture/public acceptance. Sustainability as a concept is almost universally accepted by all but the ways and means to achieve it and to cover its cost are often sources of passionate debate. One of the aspects that are hard to quantify monetarily is the return on investment in sustainable versus conventional facilities. However, more people everyday recognize the strong relationship between the performance of infrastructure facilities and a sustainable environment. A sustainable environment cannot be realized by the effort of only a few. It requires the collective effort of all because every contribution adds up toward the goal of sustainability. A course has been developed to teach the basic principles of sustainability to mainly non-engineering students with background in policy development, economics, and social and natural sciences. Infrastructure is used to communicate the message of sustainability because it is a daily encounter and the members of the public can easily relate to many of its components such as roads, bridges, clean water, waste water, ports, railways, waterways, transit, aviation, energy, communication and digital networks, etc. The main goal was to illustrate the many intertwined factors that must be reconciled to attain the goal of sustainability, and that this goal can only be achieved by team effort. The course focused on preservation and conservation of materials, better and environmentally-friendly features in designed facilities, better management and operation practices, efficient repair, and low impact decommissioning techniques. The course was also greatly concerned with policies related to infrastructure financing and new models of public-private partnership, or design-build-manage operation for a certain concession period. Students in general, and non-engineering students in particular, appreciated the multidimensional nature of the issues related to sustainability as it became clear that these are multifaceted problems that require a holistic approach in addressing them.

Introduction

Infrastructure is the society's inventory of facilities that require long term planning, construction, management, operation, maintenance, and upgrading. These are facilities used by members of the public on a daily basis. The extent to which infrastructure impact a person's daily life cannot be overstated. Infrastructure comprises vital facilities that a society cannot function without such as roads, bridges, dams, levees, communications networks, energy generating plants, power distribution grids, transportation and traffic-related structures, ports, navigation locks, airports, railroads, waste disposal, wastewater treatment, purification of drinking water, parks, etc. The public's dependence on infrastructure goes usually unnoticed until a problem occurs. Problems could arise due to aging of existing infrastructure, lack of timely maintenance, overuse, failure to upgrade deteriorating components, or natural disasters such as earthquakes, hurricanes, tornadoes, or floods. In the initial stages of planning a new infrastructure project, many engineering and non-engineering factors must be taken into consideration. Engineering factors are the responsibility of the design engineer and are tightly controlled by relevant engineering codes. Non-engineering factors are numerous and are often open for debate from concerned constituencies. Politics, economics, and social concerns are the major non-engineering factors that receive the greatest attention. In absence of a clear vision for a new infrastructure project, debates concerning the scope and features of design can drag on for a lengthy period of time. In light of a tight money supply, coupled with a desire to preserve the environment, the need to address the issue of sustainability is greatly emphasized in new facilities. Sustainability features can have an impact on a structure before construction, during operation over the life of the facility, and through upgrading, replacement, or decommissioning.

The American Society of Civil Engineers (ASCE) is immensely concerned about America's infrastructure. It attempts to raise the profile of this issue by investing time and money in gathering information about the nation's infrastructure, compiling it, issuing a report card detailing the health of America's infrastructure facilities. ASCE issued in 2009 its latest report card in which individual grades were given to various infrastructure facilities and a cumulative grade was given based on these individual grades. The cumulative grade ASCE assigned was a "D". Furthermore, it was estimated that 2.2 trillion dollars of expenditure was required to maintain America's infrastructure facilities. It is worth noting that many of America's infrastructure facilities have been constructed decades ago, and significant percentage of these facilities have reached or surpassed their intended design life. Most of the evaluated facilities received grades ranging from the equivalent to poor to mediocre condition. Under such circumstances, these facilities needed decommissioning, upgrading, or replacement.

Due to the shortage of funds necessary to meet all needs, and the significant political difficulties in appropriating the money needed for various projects, ASCE viewed sustainability as a critical element of civil engineering infrastructure. Lately, ASCE has been developing a sustainability rating system. It is intended to address the widening gap between actual infrastructure needs and available funds to tackle these needs. ASCE has embarked on a mission to educate civil engineers about the new Sustainable Infrastructure Project Rating System spearheaded by the ASCE Committee on Sustainability. Partners in this effort are American Council of Engineering Companies (ACEC) and American Public Works Association (APWA). It is also anticipated that the Federal Highway Administration (FHWA) and the U.S. Army Corps of Engineers will play a pivotal role in refining current efforts into a comprehensive rating system to address wider sustainability goals.

In its roadmap for the civil engineering profession, ASCE defines civil engineers as individuals *entrusted by society to create a sustainable world and enhance the global quality of life*[1]. Also, in its Vision 2025 for the profession, ASCE stipulates that *civil engineers serve competently, collaboratively, and ethically as master:*

- *Planners, designers, constructors, and operators of society's economic and social engine—the built environment;*
- *Stewards of the natural environment and its resources;*
- *Innovators and integrators of ideas and technology across the public, private, and academic sectors;*
- *Managers of risk and uncertainty caused by natural events, accidents, and other threats; and*
- *Leaders in discussions and decisions shaping public environmental and infrastructure policy.*

It can be seen that ASCE places great importance on sustainability as a pivotal issue in planning, design, construction, and operation. Future engineers have the added responsibility of leading discussions concerning new infrastructure facilities and educating the public to realize the prominence of sustainability as an integral factor in tomorrow's designs. Failure to shape the public's opinion on environmental and infrastructure policy matters can lead to unwanted setbacks.

Urbanization, infrastructure, and sustainability

According to United Nations' statistics, the rate of urbanization is currently about 1.3 million new city dwellers a week, which translates to 70 million a year[2]. The world was 3% urban in 1800, 14% urban in 1900, 50% urban in 2007, and probably headed in the next few decades to around 80% urban, which has been the stabilization point for developed countries since the mid-20th-century[2]. The concentration of population in smaller areas of land has many adverse effects. Congestion of population results in greater demand for services and natural resources such as food, energy, and water. Moreover, the construction of houses, roads, and other facilities replaces the natural cover of the soil with solid surfaces, such as asphalt and concrete, which alters the pattern of climate and creates the phenomena known as the heat island effect. This effect raises temperatures and elevates the demand for energy used for cooling. Solid surfaces also exacerbate the problem of contamination as storm water carries oil and grease swept from streets and parking lots.

Design of infrastructure systems is closely related to the density of population they serve. With heavier concentration of population, vertical expansion of facilities becomes unavoidable. Expanding skyward comes at an enormous cost to upkeep and to maintain various systems. Expanding downward also costs enormous capital to maintain and operate underground facilities. Rotating design philosophy is a concept in designing systems where lightly loaded components in a network help those that are heavily loaded. Theoretically, at least, this helps the system maintain equilibrium by preventing the failure of overloaded elements. Management of such vast systems is always a colossal challenge.

Infrastructure challenges

The National Research Council[3] issued a list of recommendations concerning the challenges of moving toward critical infrastructure systems that are physically, economically, socially, and environmentally sustainable. These are:

<u>Challenge 1</u>. Ensure that critical infrastructure systems effectively support competitiveness in the global economy.
<u>Challenge 2</u>. Develop the critical infrastructure systems that support responsible energy independence.
<u>Challenge 3</u>. Upgrade, renew, replace, and provide new infrastructure systems to meet current and future requirements; improve reliability; improve performance and cost-effectiveness; promote equitably public safety, health, welfare, and social equity; and protect the environment.
<u>Challenge 4</u>. Optimize public- and private-sector investments in critical infrastructure systems and ensure adequate, long-term revenue streams for their operation, maintenance, and repair.
<u>Challenge 5</u>. Improve the reliability and resiliency of critical infrastructure systems to reduce the adverse impacts of human-made and natural disasters.
<u>Challenge 6</u>. Create a base of long-term support among users for infrastructure investments.

Challenge 7. Support innovation through the development and adoption of new approaches, technologies, and materials that have the potential to improve the delivery, quality, reliability, and sustainability of critical infrastructure services.
Challenge 8. Enhance international exchange and coordination of critical infrastructure systems approaches, services, components, and materials—with respect to finance, public and private ownership structures, regulations, and other factors.

Policy trends

Recent trends in financing, maintaining, and managing infrastructure facilities show a shift toward public and private partnership. Some of these policies include: coordination and cost-sharing cooperation, management contracting, leasing and concessions, and privatization. In terms of financing infrastructure investment, some of the recent models include: shift costs to user and beneficiary groups (user fee), impose consumption fee, flexible pricing (shift demand for infrastructure services to off-peak hours or congestion fee to reduce emission and pollution), and pay-as-you-go (phase development).

Whether infrastructure facilities are being run by public or private entities, state governments are usually responsible for: setting the policy framework for infrastructure, facilitating local government, private sector, or nonprofit provision of infrastructure, regulating providers of infrastructure services to ensure that standards of quality and service are being met, providing oversight to ensure fair prices and tariffs, and guaranteeing that low-income households, rural residents, and rural businesses have adequate access to infrastructure services.

In discussing new infrastructure projects, public participation is vital especially if a project can only be realized by imposing new taxes or by passing new bonds. In democracies where freedom of speech is guaranteed, every one is entitled to his/her opinion. This can result in significant delays in urgently needed projects. Finding a common ground is the only way forward, but making concessions may not be that easy. Balancing the competing financial, environmental, engineering, safety, and other interests may not result in the best outcome for any individual factor. The goal should always be to optimize the outcome rather than to realize the best outcome for only one factor.

Politics, economics, and society

Infrastructure and politics: Infrastructure funding and decisions related to facilities are infested with politics, deal making, lobbying, mutual favors, etc. Appropriations for upgrading existing infrastructure or those for new facilities go through layers of bureaucracy that are usually influenced by politics. Infrastructure projects are sometimes used as a bargaining chip, or as a pressure tool, to pass certain laws with other provisions (or earmarking) that may not be entirely acceptable to voting politicians. Infrastructure projects may also be used as a means to get federal or state aid or to raise taxes. The state of infrastructure may be used by politicians to gain favor with voters or to expose deficiencies in opponents during election seasons.

Infrastructure and the economy: The state of infrastructure has a profound impact on economic activities. Societies need infrastructure to survive and thrive. Undertaking of infrastructure projects spurs economic activities. Large infrastructure projects provide employment to a wide segment of population, which reduces the burden of unemployment. The cycle of economic growth assumes (and expects) that infrastructure will require upgrading and replacement at certain time intervals. Societies maintaining their infrastructure in good shape are almost guaranteed superior economic growth. The considerable rate of return on infrastructure projects makes a strong case for more expenditure. Capital infrastructure projects help spark private investment in land development. All of the above activities are mainly good for the economy because they contribute to widening the tax base but side effects are also possible, such as high population density, pollution, contamination, congestion, high cost of living, etc.

Infrastructure and social behavior: Infrastructure greatly reflects on social behavior. Examples related to behavior on the road include drivers staying in lanes versus chaotic traffic; drivers courteous to pedestrians versus disregard to foot traffic; waiting in line versus aggressively cutting through it; interaction with other people using gentle language versus offending vocabulary or aggressive hand gesture; etc. Social behavior reflects on the society as a whole. People with smoothly functioning infrastructure facilities are more relaxed and less stressed. This reduces friction, conflict, and crime in the community (road rage, for example).

Public views and culture

The worth of infrastructure could be determined based on the monetary value of a physical structure (e.g., a bridge, road, water treatment plant), a valuable commodity (e.g., time), or a means of enjoyment and satisfaction (e.g., convenience). To calculate the worth of an infrastructure facility, one needs to price time and convenience. This is oftentimes difficult and controversial, but not impossible if done with objectivity. Societies that prize time and convenience are willing to pay high premiums for such items. The worth of the physical facility may decline or depreciate over time but the worth of time and convenience is likely to remain the same or even increase. The worth of infrastructure is a complex subject with many parameters and varying viewpoints. The fact that remains unchanged, and unchallenged, is that: infrastructure worth divided by the number of individuals benefitting from the facilities equals extra income and improvement in life quality. The greater the worth the higher the value gained by every member in the community.

Another important factor that must be realized in designing sustainable facilities is eventuality of infrastructure change. Human ingenuity will continue to find new ways to improve existing infrastructure facilities. The motives for better service, economical facilities, and lower cost will always drive humanity for change. Change is eventual but if it does not happen in a timely and organized fashion, market forces take charge and force it. The public's culture may embrace or abandon change. Embracing change is a sign of moving in a new, and more often than not, better direction. Abandoning change is a sign of lack of public interest or absence of enthusiasm to cause or implement change. Whatever the reason for change is, it is meant to be for a better outcome, and should always lead to more prosperity. Change that slows or hinders progress is dead on arrival. Evolution-centered change due to policy, public pressure, the environment, etc. is a natural outcome of society development. Communities are in constant pursuit of new ways to advance their goals. Resisting change due to fear of change is groundless and must be rejected.

Scope of sustainable design

There has been a considerable shift in the way infrastructure facilities are being designed. This paradigm of the "new economy" places a significant emphasis on sustainable design, which allows constructed facilities to be more environmentally friendly, easier to manage, and have longer life. Some of the methods toward achieving these goals include:

- Less energy consumption
- Less material use
- Emphasis on reuse and recycling
- Focus on environmental and climatic impact
- Smart and efficient infrastructure
- Monitoring and sensor technology
- Assessment of performance
- Public awareness and education

The degree of impact of each of the above factors on the design of sustainable facilities varies depending on the type of the facility under development. It must also be recognized that many infrastructure facilities serve in an open environment where they are constantly subjected to the elements. Under such circumstances, design provisions must cope with nature rather than resisting it. Furthermore, it should be emphasized that patterns of climate change or rising water levels be incorporated in project design to assure sustainability for the longest possible period of time.

There are also new realities that require different design and management techniques. This includes: the danger of depletion of resources, the emphasis on recycling and sustainability, the aging of population in developed countries, the high percentage of youth in developing countries, and the aging of infrastructure that reached the end of its design life. In addition to traditional natural sources of hazard such as earthquakes, tornados, hurricanes, and floods new unconventional threats to infrastructure include man-created explosions and other destructive acts. These are all factors that require higher levels of security and greater provisions for safety. They also demonstrate the need for an unorthodox approach for design and management. One cannot ignore the fact that the world is no longer defined by the boundaries between its countries. The fast and easy communication and transportation methods made Planet Earth like a global village. This sphere is where humanity existed from the beginning of history, and where it continues to exist today. Humans are faced with some extraordinary challenges that must be addressed immediately in the design, construction, and management of infrastructure facilities. These challenges call for the use of new, smarter, and efficient materials, the adoption of new methods and processes in manufacture, the implementation of new practices in operating facilities to lengthen their useful life and to reduce the cost of maintenance, and overcoming long standing inefficient management approaches that rely heavily on the human factor. Systems monitoring and management can be done today using sophisticated software and wireless devices. Improvements of methods of planning, design, construction, maintenance, and management are only possible with monitoring and assessment of facilities performance. Record keeping and well documentation of performance are greatly important in enhancing future facilities performance. This can optimize the functions of all components in a system. In addition, it can communicate information as changes happen without any time delay, which can enhance the decision making process.

Course development and assessment

The issues presented in the above demonstrate the necessity for future engineers and concerned citizens to understand how sustainability must become a way of living. It is imperative for tomorrow's decision makers to appreciate the depth and breadth of the problems that Planet Earth may face due to unsustainable pace of resource depletion. The developed course aimed at teaching the basic principles of sustainability to students from various backgrounds. Infrastructure facilities were used to illustrate the issues at stake as they are a daily encounter and the members of the public can easily relate to many of its components. Students gained insight into the many intertwined factors that must be reconciled to attain the goal of sustainability, and realized that this goal could only be achieved by team effort. It was evident that the subjects of infrastructure and sustainability enjoy sizable appeal with many segments of the student population. This natural appeal is an opportunity and a challenge at the same time. The opportunity is due to the fact that such a course can be used to shape young minds to appreciate the need for sustainable infrastructure facilities. The challenge arises from the fact that many of the non-engineering students that take such a course have limited technical background that makes it difficult to teach intricate engineering principles. Thus, it is imperative to approach the subject matter in a balanced manner that will simultaneously win the engineers and not turn off the non-engineers. This is no easy task but is achievable with proper preparation and the extensive use of real-world examples that illustrate the points being made. Official course evaluation indicated that it was well received. The course earned high marks for the teaching approach that blended technicalities with policy.

In addition to exams, class discussion, and participation, the course required each student to research and write a term paper on a subject of their choice. Each student's selected subject has to address the themes of both infrastructure and sustainability, and students were required to receive the instructor's approval of their chosen subjects one month prior to the paper's due date. These papers proved to be an excellent venue for students to report on a subject that interested them. The variety of the selected topics and the depth with which these papers were written were gratifying. In addition to the written report, each student made a class presentation followed by questions and answers period. It was evident that students were totally invested in their selected topics and were excited to share their findings with the class. It should be noted that due to the dynamic nature of the subjects of sustainability and infrastructure, future course offerings will require constant updating of the materials taught.

References

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