Introduction

"Focus first on those aspects of infrastructure that provide essential services, that is, those involving drinking water, wastewater, transportation, energy, and communications. ... Business and population growth have already outpaced the capacity of existing systems. To meet user's expectations, planners should first determine the public's expectations with respect to the levels and resiliency of such services and the amount of money that should be spent to maintain them and then determine what alternatives exist and what actions need to be taken to meet those expectations."[1]

Toward More Sustainable Infrastructure: Better Projects and Better Programs

Modern societies depend upon vast infrastructure-based systems that support efficient transportation and communications, provide ample supplies of clean water and energy, and enable effective treatment and disposal of wastes. The performance of such systems can be measured in terms of many factors, including cost, energy consumption, resource requirements, capacity, service quality, safety, impacts on society, and impacts on the environment. Performance can also be measured in terms of sustainability, a broad concept that refers to the ability of a system to perform well over a very long period of time.

Sustainability is a particular concern for systems that rely heavily on non-renewable resources and systems that result in severe degradation of the environment. However, troubles in any aspect of performance can limit the sustainability of an infrastructure-based system. Sustainability can be enhanced by reducing costs, improving social and economic benefits, restricting the use of fossil fuels and other non-renewable resources, or reducing negative social and environmental impacts.

Many infrastructure projects and programs are aimed at improving some aspect of sustainability. Some are designed to ensure that the system continues to function properly. If infrastructure is inadequate or poorly managed, people may suffer from congestion, high costs, pollution, economic stagnation, or environmental degradation. To limit such problems, on-going investments may be required in new facilities, better materials, or new management techniques, although the nature of the infrastructure may remain about the same. Highways in 2016 may have real-time information signs, better paving materials, and synchronized traffic signals, but they still look and function much as highways did 50 years ago.

Other infrastructure projects and programs are designed to replace or upgrade systems that for some reason have become obsolete or non-sustainable. Over time, as economies develop, as societal norms change, and as certain resources become less available, the demands on infrastructure systems will change along with public perceptions of infrastructure performance. If infrastructure systems fail to evolve, they may eventually be recognized as being too costly, unsafe, disruptive to society, or overly-damaging to the natural environment. At that point, new systems are needed. For example, solar power and wind power can produce electricity that otherwise would have required additional power plants and more imported oil.

In short, infrastructure projects and programs are designed to improve some aspect of system performance. Better projects and better programs will lead to more sustainable infrastructure. The problem is how to determine which projects and which programs are better.

---

[1] One of the conclusions of *Sustainable Critical Infrastructure – A Framework for Meeting 21st Century Imperatives,* a report based upon a May 2008 workshop sponsored by the National Research Council ("Report Urges New Framework for Planning Critical Infrastructure." *Civil Engineering.* June 2009. p. 20.)

Infrastructure Projects and Programs

Infrastructure projects include large-scale, multi-dimensioned, long-term investments in transportation systems, buildings, water resources, communications, power generation, parks, schools, and other public services. Such projects always have multiple objectives, they will often be controversial, and people with many different perspectives must come together to complete the projects and make them successful. Such projects have important impacts for the public at large, because they will affect the environment, our society, and our economic prosperity. A program consists of a set of related projects, such as the Interstate Highway Program or a program designed to promote investment in wind power.

Historically, there have been numerous large-scale infrastructure projects and programs, some brilliant, some misguided, and many of them quite interesting for planners and engineers, such as the Panama Canal and skyscrapers in Manhattan. Projects like these affect the way we live, they are the backbone of much of our history, and they are the pathway to our future.

This book is about understanding where projects come from, how they are evaluated, how decisions are made to proceed with them, and what separates good projects from bad projects. This book spends considerable time on methodology, especially the methods of engineering economics that can be used to understand how projects are financed, but it also provides real-world examples and case studies that convey some of the flavor, excitement, and challenge of designing, evaluating, and implementing projects.

Figure 1
The Panama Canal

After decades of frustration, tens of thousands of deaths from tropical disease, bankruptcy and disgrace for the initial French Canal Company, the canal was finally was completed in 1914 and remains today a critical link in global transport and a highly profitable enterprise for Panama.

Implementing, operating and maintaining infrastructure requires planners and engineers to work with bankers, entrepreneurs, politicians, community leaders and the public in order to meet society's needs more effectively. Planners and engineers must learn to deal with the social, financial, and environmental issues related to infrastructure projects, and these issues will become more important over time. Engineers are likely to start out building and designing projects, and many engineers spend their entire careers concentrating on these activities. Planners and

managers are likely to start out working at a low level on projects and programs that were begun years ago. However, someone, somewhere, is trying to figure out what to build next, when and where to build it, and how to convince investors and governments to pay for it. Actually, there are many such people, and some of them are destined to become famous. These people may end up proposing projects, or they may simply define problems and convince other people to begin working on them.

Engineers, planners and managers naturally expect to work on large-scale infrastructure projects. To succeed and to advance in their professions, they will need to understand the big picture - the needs of society - in order to take the lead in designing, implementing or marketing new technologies or new systems. Leaders will need a broader outlook on problems than is ordinarily conveyed in an engineering subject or a textbook on finance. They will need to understand how projects begin, how they are sold to the public, and how they become successful. They will need to combine engineering or planning skills with marketing, financial, and communications skills. Anyone who grasps this broader outlook will have a chance to become involved in projects and programs that are increasingly complex, with more possibilities for design and implementation strategy, less certainty regarding the outcomes, and greater need for imagination and leadership.

Infrastructure is usually defined in terms of public systems, and constructing and maintaining infrastructure is an on-going process and problem for local and national governments. Infrastructure refers to the physical systems that provide transportation, water, buildings, and other public facilities that are needed to meet basic societal needs. These facilities are needed by people regardless of their level of economic development. When infrastructure is not present or does not work properly, it is impossible to provide basic services such as food distribution, shelter, medical care, and safe drinking water. Maintaining infrastructure is a constant and expensive process that often is neglected in favor of more attractive political goals.

In practice, much of the civil infrastructure may be owned and maintained by private companies or individuals. Much infrastructure was originally built by private corporations with licenses or other authorization from government; private toll roads were the norm in the United States in the early 19th century, and private expressways are being built today in many parts of the world. Many railroad systems are privately owned and operated. Large office buildings or apartment buildings are mostly privately owned, and they are certainly part of the basic infrastructure of a modern city.

Project evaluation may involve assessment of proposed options for creating, maintaining, rehabilitating or decommissioning any kind of infrastructure, whether carried out by the public sector, the private sector or a public/private partnership. Thus, building a new road, adding a lane to an existing road, or paving an existing road could all be considered infrastructure projects. For administrative convenience, a large project will often be broken down into multiple smaller projects. The construction of a new road may involve construction of a dozen bridges, three major interchanges, extensive cut-and-fill operations to prepare the right-of-way, and eventually the actual paving of the road. Moreover, the road may be completed in multiple phases over a period of many years. Whether to consider each of these activities as a separate project, each phase as a separate project, or the entire road as a single project could be debated; there will certainly be a well-defined set of contracts and sub-contracts so that all of the contractors have a clear perspective on their portion of the overall project. The public, however, will likely view the whole road construction as a single, multi-phased project. The distinction is usually unimportant, although there will be times that a small segment of a road (or a small portion of some other project) will be proposed, hoping to gain approval more easily later on for an extension after “getting your toe in the door”.

An infrastructure program may be established as a way to manage a series of projects or a way to simplify the design and approval process for multiple projects. A program may specify goals and criteria for measuring progress against those goals. It may also specify what kinds of projects will qualify to be included in the program and what kinds of incentives will be available to qualifying projects. For example, a state may establish a program aimed at attracting private investment in housing for low-income families. The program may provide subsidies, tax relief, or other benefits to projects that qualify according to the criteria specified in the legislation or regulations. A company may also have infrastructure programs; retailers such as Home Depot or Wal-Mart will have plans for expanding their

network of stores and warehouses. A railroad may have a plan for upgrading its oldest bridges on certain high density lines; each bridge renewal would become a separate project as a part of the program. Cities and states may have programs aimed at providing housing for the elderly or for low-income residents, and they may have programs aimed at improving water supplies or sewage treatment facilities. The various interest groups and political leaders who favor or oppose a certain type of project will fight over the structure of a program, perhaps for many years, but eventually they may reach agreement about the objectives, scope, funding amounts, and funding eligibility for the program. Once a program has been established, those prolonged fights will cease, and projects can rather quickly be identified, approved, and implemented. It will be desirable from time to time to review programs to ensure that the objectives remain valid, that the funding mechanisms are adequate and fair, and that the projects as implemented under the program actually have been achieving the program's objectives.

Infrastructure projects and programs have several common and very interesting aspects:

- Infrastructure is intended to last a very long time, so it is necessary to compare what may be very large current expenses with the potential for benefits that will be gained only over a period of decades.
- Infrastructure influences and perhaps defines the location and land use of cities and regions, so the location of infrastructure will have long-term implications for local and regional land use.
- Infrastructure often involves networks of facilities that are widely dispersed, perhaps with severe consequences for the environment or for the people who live where the networks are located.
- Infrastructure benefits are frequently qualitative or difficult to measure, e.g. mobility, safety, air quality, or the availability of clean water.
- Infrastructure projects and programs will be of great concern to many different groups of people, including developers, the public, special interest groups (some of which may be public interest groups and some of which may be supporting very narrow private interests), governments (including elected officials, regulatory officials, and administrative officials), lawyers, users, abutters, construction companies, and investors.
- Infrastructure is costly to build and costly to maintain.

The long lives expected for infrastructure cannot be achieved unless funding is available for proper management, including safe operating practices, on-going inspection and maintenance, and periodic renewal and upgrades. Without such funding, infrastructure systems will deteriorate and eventually be unable to meet the societal needs they were designed to serve. Without adequate funds for renewal and expansion, it will be impossible to meet growing needs for services or to capture the benefits of new technologies.

Adequate financing must therefore be considered an essential factor in improving the sustainability of infrastructure systems, where "sustainability" refers to the ability of a system to function long into the future. Poorly managed infrastructure systems that steadily deteriorate, become congested, or become unsafe clearly are not sustainable. However, adequate financing is but one of the major factors affecting the sustainability of infrastructure.

Large-scale infrastructure, even if it appears to be adequately financed, can only be sustained over long periods of time if it is supported by society and the resources it requires are available at a reasonable cost. If infrastructure requires excessive use of non-renewable resources, if it requires too much water or energy, or if its use results in devastation of the environment, then the lack of resources, increasing costs of materials, or public outrage will force changes. If construction, maintenance, and operations continually disrupt neighborhoods, cause human suffering, or expose people to potentially catastrophic risks, then society will be reluctant to support further expansion of that kind of infrastructure.

Over time, social norms may change, the costs of resources may vary, and new technologies may emerge. What one generation viewed as highly beneficial investments may be viewed as dubious achievements or even disasters by following generations. Infrastructure systems must evolve along with society, and rising concerns about public safety, public health, climate change, pollution, environmental decline mean that society will require more sustainable infrastructure. Water shortages, highway fatalities, urban congestion, over-dependence upon fossil fuels, toxic chemicals associated with large-scale agriculture, acid rain, oil spills, and excessive amounts of solid waste are all

symptoms of problems that reflect a need for more sustainable infrastructure and a more sustainable way of life. Challenges such as those posed by climate change, oil depletion, collapse of fisheries, and large numbers of endangered species combine to make stewardship of the environment and sustainable development greater concerns for society.

Achieving more sustainable infrastructure will require thought, innovation, planning, financing, regulation, and leadership. There clearly is a continuing need for large investments in infrastructure, and there will be many opportunities for evaluating projects and programs related to all types of infrastructure. Evaluating projects and programs will require methodologies for comparing current and future impacts, for considering multiple objectives, for assessing both quantitative and qualitative information, and for communicating and negotiating with diverse groups of people.

Evaluating Infrastructure Projects

The main goal of project evaluation is to help in identifying and implementing successful projects and programs. From an overall perspective, a project is successful if:

1. It was built, which proved that construction was feasible from engineering, financial, and social perspectives.
2. The benefits were indeed greater than the costs.
3. The project as built was an effective way to achieve those benefits.
4. The project was built in an efficient and effective manner:
    a. There were no clearly better options.
    b. There were no significant negative externalities.
5. Building this project did not foreclose other, even better projects.

Different participants might have far narrower definitions of success. Did the engineers design a building that was safe? Did the contractors get paid? Did clean water actually come to the neighborhoods? Did the mayor get re-elected? These different perspectives must of course be considered in evaluating projects, but it is useful for students, consultants, concerned citizens, honorable developers, and honest politicians to pay some attention to the overall issues.

Project evaluation is a qualitative process as much as it is a quantitative one. A critical step is to create a "story" for the project that can be used to explain why the project is needed, what it will do, what the benefits and costs will be, and why this is the best way to proceed. There will certainly be quantitative aspects to the process, although estimates of costs and benefits may be rather ill-defined and subject to debate.

Implementing and maintaining a project over a long period of time will require:

- Financing: sufficient income to cover expenses, whether the income comes from user fees, investors, subsidies, or contractual payments.
- Government approvals: licensing and periodic inspections to ensure compliance with safety, environmental, and other regulatory matters.
- Engineering skills: sufficient knowledge and skilled manpower to conduct the maintenance and rehabilitation necessary to perform at an acceptable level of service.
- Resources: people and materials as required for maintenance and operations and whatever additional resources are needed by users (e.g. asphalt for highway maintenance plus gasoline for drivers).
- Public support (or tolerable opposition and interference).

The financing issue is different from the economic issue. Financing provides the cash necessary to construct, operate, and maintain a project. The ability of a project to be financed depends upon the availability of money – not upon the actual economic benefits of the projects. Economic issues concern the costs and benefits associated with a project,

the distribution of those costs and benefits, and whether the benefits are sufficient to justify the costs. Economic benefits may include creation of jobs, congestion relief, reduction in accidents, or improved productivity for those affected by the project. Some of these benefits may be easily described in monetary terms, and some may be very difficult to quantify in monetary or any other terms. They are economic benefits because they allow more efficient and more effective use of resources, even if the benefits do not translate directly into cash for the project or for investors.

It may be helpful for a project to have economic benefits in order to attract public or private financing. For example, governments may choose to subsidize transit operations, housing for low income or elderly residents, or agriculture. The cash provided by those subsidies can in fact attract investors, who will create commuter rail services, apartment buildings, and more productive farms. Whether or not these projects are really worth the subsidies that they receive is important for legislative bodies and elected officials to consider, but not necessarily something that will concern investors.

Government approval will be needed for any almost any project. A building permit will be needed for constructing a screen house in your back yard or for constructing a 100-story office building. Governments may establish regulations concerning land use, protection of the environment, the siting and size of buildings, construction materials and methods, the use of union or local labor, and many other factors that may affect the feasibility, cost, and ultimate success or failure of the project. Whether or not government agencies approve proposals or provide the necessary permits may depend upon legislation, regulations, the whim of administrators, and/or feedback from the public. Large projects tend to generate large criticism, so developers must always be concerned with public perceptions of their projects and they must be aware of ways to make their projects more attractive to the public.

People with the necessary skills are needed in designing projects, in constructing them, and in ensuring they continue to function. It is one thing to build a road. It is another thing to enforce weight limits to ensure that overloaded trucks do not destroy the pavement within a few years, to enforce speed limits so as to promote safe driving conditions, and to establish periodic inspections, maintenance, and rehabilitation to keep the road in safe condition.

Projects and the people who use them or depend upon them will need resources for operations and maintenance over what may be a very long lifetime. Projects may fail because the resources needed to sustain them become too costly or unavailable. Some of the most pressing issues of the 21st century relate to the continued availability of fossil fuels for transportation, electrical power generation and home heating, and the availability of water for irrigation, household consumption, and industrial use. Many projects and infrastructure choices were justified based upon usually unstated assumptions that unlimited supplies of cheap oil and water would always be available. Fossil fuels, however, will not last forever, and prices will rise as reserves of oil, coal and natural gas are used up. With cheap oil, automobiles and airlines prosper; with expensive oil, transit and rail transportation become more competitive. With abundant water supplies, crops can be grown in irrigated deserts, people can compete for the greenest lawns, and industries can use processes that consume vast amounts of water. Eventually, however, as population growth and other demands for water increase, the supply of water is no longer sufficient for all the possible uses, so the use of water will be regulated and the price of water will rise. Moreover, water supplies may diminish. Regions that are heavily dependent upon well water may find that their aquifers are drying up. In other regions, changes in climate may diminish the amounts of water that is available. Since drainage and river basins follow geographical rather than political boundaries, rival demands for the use of water have and will continue to spark political battles between neighboring states and countries. A populous region, such as the Los Angeles metropolitan area, will seek to divert water from distant regions in order to support their needs, while perhaps limiting the growth and productivity of the regions from which the water is diverted. Disputes over oil reserves have already sparked conflicts in the Middle East, and the potential for future conflict will continue as long as so much of the world's transportation, power generation, and industrial production is fueled by oil.

Public support, or at least tolerable opposition, is the final factor necessary for the long-term success of a project. The public normally does not have a direct role in decisions regarding major projects, as most decisions regarding projects are made by elected officials, appointed officials and legislative bodies. However, the public can provide input into

the decision process, whether by participating in a process established to promote public involvement, by writing to newspapers or elected officials, or by organizing groups to support or oppose projects. Public opposition can prevent particular projects, it can lead to new regulations or legislation, and it can change programs and policy. In the late 1960s and early 1970s, public opposition was the major factor in halting construction of major urban portions of the Interstate Highway System, including the so-called Inner Belt and the Southwest Expressway in Boston and the Embarcadero in San Francisco. Public concerns over the safety of nuclear power plants had led to stringent regulation of the construction of such plants in the US by the 1970s; public outrage after a rather minor leakage incident at the Three-Mile Island Nuclear Power Plant effectively halted construction of such plants in the U.S. for decades.

Infrastructure, Cities, and Civilization

It can be argued that infrastructure projects are the key to urbanization, which is perhaps the chief characteristic of civilization. If people are to be able to congregate in cities, then they will need access to large amounts of clean water, and they will need to have some system for treating or isolating wastes. They will need to import food, building materials, and energy resources. They will need facilities and materials to support various kinds of manufacturing and trade. They will want to create facilities for education, sports and worship, for communications and entertainment. In short, people will have to construct the infrastructure necessary to support all of the normal functioning of a densely populated society.

> *Your imagination, your initiative, and your indignation will determine whether we build a society where progress is the servant of our needs or a society where old values and new visions are buried under unbridled growth. For, in your time, we have the opportunity to move not only toward the rich society and the powerful society but toward the Great Society. The Great Society rests on abundance and liberty for all. It demands an end to poverty and racial injustice, ... It is a place where the city of man serves not only the needs of the body and the demands of commerce but the desire for beauty and the hunger for community. ...*
>
> *Our society will never be great until our cities are great. ...*
>
> Lyndon B. Johnson, President of the United States,
> excerpts from the "Great Society Speech" delivered at the University of Michigan, May 22, 1964

The benefits of urbanization can be great for people's lifestyles and for efficient use of resources. Higher populations can support a diversity of lifestyles and greater opportunities for jobs and recreations. There can be a greater frequency of and higher quality for social events. When people no longer have to spend all of their time eking out a living, whether on a farm or in isolated rural areas, they will have sufficient time to enjoy the fruits of civilization. From a systems standpoint, having large numbers of people living in a small area allows more efficient use of resources in constructing and operating transportation networks, creating housing, supplying water and treating waste. As activities are differentiated, complementary activities can be concentrated within special districts of the city. When people are concentrated in well-situated cities with sound infrastructure, they can be protected from natural disasters, and it is possible to manage development so as to reduce the consequences of manmade disasters.

Of course, as Freud pointed out in his book *Civilization and Its Discontents,* crowding vast numbers of people into cities may not be good for everyone. The more we protect ourselves from natural disasters and the more contact that we are forced to have with each other, the more difficult it may be for us to live together. There is not only the loss of self-sufficiency that may be achievable on a farm, but there is also the possibility of extreme poverty. A city is dependent upon its infrastructure – and transportation or water resource systems may fail. If diseases break out, thousands may die, and pollution and the inability to absorb wastes may become continuous drains on health and happiness. As cities grow ever larger, congestion is likely to limit mobility, and it may become ever more difficult to limit pollution, to provide open space and to ensure adequate housing for everyone.

Whether cities evolve into safe, livable, aesthetically pleasing places or degenerate into overcrowded dens of despair depends to a very great extent upon the ability of the people of those cities to undertake the projects that will enable them to meet the needs of human life and challenges of urban life. Anticipating and responding to challenges is the driving force for successful civil and environmental projects. And there will always be new challenges.

Tomorrow's challenges may be quite different from yesterday's, but there will always be basic needs to be met and there will always be a need for evaluating and choosing the best ways to meet those needs. Even with tremendous advances in communications and computers, with automated factories and computer-controlled highway networks, with cheap transportation for freight, a global economy, and ever-improving medical care, there will still be plenty to do. After all, only about half of the world's population has access to clean running water; hundreds of thousands of people die each year in transportation accidents; earthquakes and other natural disasters cause thousands of fatalities; billions of people live in substandard housing; and nearly everyone who lives in a large city spends a large portion of their life stuck in traffic and breathing bad air.

Where Do Projects Come From?

A project begins long before the groundbreaking, long before the first contract is signed, and long before a specific plan is identified and agreed upon by people with the resources and political power to make something happen. A project begins with an idea, with a vision of what is wrong or what is needed or what is possible. Initial ideas quickly evolve into whole families of ideas and possibilities and soon different, competing options begin to emerge. Long before the time for computer analysis and project planning, strong-minded, imaginative, entrepreneurial, and political individuals are vying to promote their concepts for the future. The players might include engineers, politicians, charlatans, financiers, developers, or dreamers. There are no bounds to how they might think or talk about the project, or how they conceive the project fitting in to what is already in place or what could be put in place. Their creative processes can be slow or rapid, rational or chaotic, cooperative or acrimonious – there are no rules and there are no limits to how hard people will push.

This undisciplined, often unmannerly process eventually leads to a specific project that will be constructed to finely drawn plans with a well-defined scheme for paying for it all. At this point, and not before this point, project management skills are needed, and there will be plenty of work for those with specialized software, algorithms, and risk management techniques that can lead to more efficient designs and timely completion of the project. But those skills are not much use in the early stages of project design and evaluation.

It is these early stages where there is the greatest uncertainty, the most excitement, the widest opportunities for egregious errors, and the best chances for achieving elegance in a project. It is difficult to teach how to conduct this process for which there are no rules and few guideposts. By the time that the processes are well-enough defined to create guidebooks for planners, the damage of poorly conceived projects will be only too apparent. We built highways straight through cities for decades before stopping to think seriously about the effects on the neighborhoods and the possibility for justifying less disruptive, more effective approaches. We need to think before we leap, we need to appreciate the creative, political, and entrepreneurial efforts that are needed, and we need to avoid the pitfalls that can catch the unwary.

A Framework for Project Evaluation

Project evaluation can be broadly conceived to include five phases that cover the entire life-cycle of a project:

1. Project identification
2. Analysis of alternatives
3. Assessing and comparing alternatives
4. Implementation
5. On-going evaluation

The first three phases may require many iterations before a final project is approved, and the final phase should continue over the entire life of a project.

Project Identification. The first phase is the least well-defined and yet the most important for the ultimate success of a project or a program. Many ideas for projects arise in response to perceived problems and the needs of society. Congestion leads to ideas for new roads or new transit systems. Rising populations require new schools, housing, and drinking water. If problems and needs are understood, and if there is a process for examining possible ways to deal with them, then it should be possible to develop effective projects and programs that result in a better society. However, there will not necessarily be any process for determining and responding to societal needs. The ideas for many projects may originate when someone senses an opportunity to make some money or to create some sort of monument. Ideas for projects might well come from someone – an entrepreneur, a company or a public official - who spots an opportunity for using a new technology, for developing a particular plot of land or for expanding an existing network of facilities. It may well happen that project proponents first identify the project and then address the problems or needs that would be addressed by this project.

Nevertheless, it is useful to have a framework in which the first step examines problems or needs. For an infrastructure-based system, problems are likely to relate to cost, capacity, service quality, or safety. A problem may exist if some aspect of performance is believed to restrict the efficiency or effectiveness of the system. System operators will likely be aware of ways to improve performance, based upon their own insight into operations or based upon comparisons with similar systems in other locations. A need for better performance may be evident from user complaints, media reports, or scientific studies. Needs may be expressed in terms that are much different than the terms used to define problems. For example, transportation needs might be expressed in terms of mobility and accessibility, whereas transportation problems might be expressed in terms of travel delays and maintenance costs.

The objectives of the project need to be clear and well defined, but they can be modified based upon feedback and assessments concerning completed projects or new information related to needs and opportunities. The need for flexibility may lead to certain challenges in the overall decision-making and implementation process. Sometimes strategic objectives are too narrowly defined and remain fixed despite changing conditions and acquisition of new information. Sometimes objectives are in conflict with objectives of other programs, particularly in the public sector, so that projects can only be developed after due consideration of related programs.

The next step is to generate alternatives for addressing the problems and needs that have been identified. Problems and needs should be considered in general terms, so that different kinds of alternatives can be considered. For example, many systems must deal with potential capacity problems related to growth in population. If so, then alternatives could not only consider expanding capacity to keep pace with population growth, but also consider increasing prices in order to limit demand or increasing efficiency of operations in order to allow more effective use of existing capacity.

The project identification phase concludes with a clear statement of needs, a set of objectives and specific assessment criteria, and an initial list of alternatives for achieving the objectives. Key results from this stage of project evaluation include clear statements of needs and objectives, the establishment of criteria, and the selection of alternatives for further study.

Analysis of Alternatives. The process then enters the analysis phase, in which studies provide information that will help in assessing and comparing the various alternatives that are being evaluated. Various studies will be necessary to assess the viability of each alternative with respect to technical, financial, operational, social, economic, environmental or other objectives. Considerable discussion and thought will be devoted to identifying performance measures and evaluation criteria for each major objective. Preliminary studies may give an early indication of the viability of an alternative, along with the risk involved. The most promising alternatives will be studied in greater depth. Analysis may include market demand studies, cost-benefit analysis, environmental impact assessment, and social assessment. Very detailed analyses involving multiple groups of people with backgrounds in engineering, economics, environmental science or other disciplines may be required. Important planning decisions during this

phase of project evaluation include the allocation of resources to the different types of studies and the extent to which the process allows refinement and modification of alternatives.

Assessing and Comparing Alternatives. Assessing the results of the analysis is a separate stage from analysis, because there will be many different kinds of results to be considered. During this phase, it will be necessary to compare alternatives with respect to how well they satisfy the objectives that were previously established. Assessment will involve consideration of financial, economic, environmental and social factors. To what extent does each alternative meet the needs that are being addressed? What are the costs and benefits of each alternative? Are costs and benefits measured properly? To what extent does each alternative lead to positive or negative externalities, i.e. to broader impacts on the environment or the community or the region that would result from implementing a particular alternative?

Whereas analysis requires specialists and may include many independent studies, assessment requires generalists. For public projects and for large private projects that require public approval, there will have to be opportunities for input from potential users, abutters, and the general public. Users may push for a bigger and better system. Abutters, those who live next to the construction sites, may like the concept of the project, but oppose the proposed location. This type of opposition is so common that it is known by an acronym - NIMBY – which means "Not In My Back Yard." The general public, to the extent that is informed about the issues, is likely to be more receptive to a more balanced approach that recognizes the potential benefits of the project while acknowledging the importance of externalities.

The goal at this stage is not necessarily to define the exact, best option, but to determine the general approach that is best. The outcome from this stage could be one of three broad conclusions:

- One alternative clearly is the best.
- Further study is necessary to determine which alternative is best.
- None of the alternatives is worth pursuing.

If one alternative is clearly the best, then it is possible to proceed to the next phase. If there is no alternative that is clearly the best, then more detailed analysis may be needed that focus on what are believed to be the most promising alternatives. It may also be desirable to revise some of the alternatives or to suggest new alternatives or different kinds of analysis. This phase of the evaluation process requires the consideration of multiple objectives as well as risk assessment in order to compare what could be markedly different alternatives. It also requires some mechanism for ensuring that there are no better alternatives that should have been studied, as well as a mechanism for determining that the preferred alternative in fact is a cost-effective way of meeting the needs identified at the outset. Table 1 suggests some guidelines for this phase of project evaluation.

Implementation. Project identification, analysis and assessment are iterative processes that may continue for years or decades without finding an alternative that is technically, financially, and politically feasible. Eventually, it may be possible to agree upon a particular alternative. The fine-tuning of a particular alternative may involve mitigation of environmental or social impacts, it may involve modifications aimed at reducing costs or increasing benefits (a process known as value-engineering), and it may involve modifications to incorporate recommendations resulting from public input or the various studies that were conducted. At some point, detailed engineering design can be completed, and a construction management program can be initiated. A strategy for construction must be developed. How soon should construction begin? How quickly should construction proceed? What are the possibilities for implementing the project in stages? Once these questions have been answered, a project management team will be in charge of the actual construction process, and there will be innumerable decisions related to the best construction techniques, logistics, coordination of sub-contractors, communications and cooperation with relevant public authorities and maintaining the safety and security of the site. Before construction is complete, it will be necessary to begin the transition from to operation. Eventually the construction phase ends and the project is up and operating: the bridge is open, the tenants are in the building, the water is flowing, or the park is opened to the public.

Table 1 Guidelines for Assessing Projects

1. Address the grand issues.
    - Economic viability – is there a clear case for supporting the project?
    - Engineering – what are the options regarding capacity, staging, and flexibility?
    - Financial feasibility – is there a way to cover investment and operating costs?
    - Environmental impacts – can the project be done with less negative impact on the environment? Can it result in improvements to the environment?
    - Political feasibility – who is likely to support or oppose the project? How can negative social impacts be mitigated?
    - Organizational structure – is the project best done as a public project, a private project, or a public/private partnership?
    - Size – would a larger or smaller project be better than what is proposed?
2. Consider comparable projects to get a quick, though rough estimate of the viability of the project.
3. Consider the possibility that the benefits are so great that there is more danger from doing too little than from doing too much.
4. Be prepared to think at all scales: local, regional and national.
5. Think about aesthetics and plan with an eye to style.

On-going Evaluation. Few projects are so well-planned and so carefully executed that everything goes perfectly on day one of the transition. There will be a period of time during which minor problems will be identified and corrected. After operations have settled down, it will be possible to compare the actual performance to what was intended. Was the project completed as planned? Was it completed on time and on budget? Most importantly, how effectively has the project addressed the original problems and needs? Answers to questions such as these will help in planning the next project and perhaps help in creating criteria for a program for constructing many similar projects.

In summary, the process of defining a project can be viewed as a logical sequence of well-defined steps beginning with identification of needs and concluding with on-going monitoring of performance. While it is useful to have a framework such as this for thinking about projects and project evaluation, it is important to recognize two fundamental aspects of the process of defining and selecting projects.

First, the process is iterative. It may begin either with identifying needs, technological opportunities, or with an idea for a specific project. Once assessment begins, new ideas may emerge or people may find serious problems with all of the proposals, so it will be necessary to reconsider the needs and the opportunities.

Second, the process may not necessarily be logical or rational. Suggestions for projects may come from those who want to build them or from those who want to operate them – whether or not the projects they propose are the best projects or the projects that respond to the most pressing needs of society. Companies that build roads and bridges want to build more roads and bridges, just as highway authorities may respond to all transportation problems by recommending construction of more highways. New technologies quickly lead to ideas for new projects, but it may be years or decades or longer before those projects can be justified. With many new technologies, the new capabilities create new needs, or at least perceived needs (continuous, instantaneous connections to the internet; high definition TV). With advertising, suppliers can create needs that drive construction of new plants and distribution facilities (bottled water is a good example – especially when the water is obtained directly from a region's public water supply). It is a mistake to expect the process to be completely rational. On the other hand, it is also a mistake not to try to

impose a rational process on defining needs, identifying alternatives, and assessing, selecting, and modifying alternatives.

Essays and Case Studies

This book includes a collection of essays and cases studies that address the many phases of project evaluation. The first volume provides a framework for understanding and evaluating projects, taking into account not only the financial and economic issues, but also social and environmental factors. Examples and case studies illustrate the complexity of major projects and demonstrate the role for and the limits of analysis in clarifying and resolving issues. The second volume shows how to apply the basic methods of engineering economics in evaluating major infrastructure projects. Examples and exercises indicate how to develop and apply models for estimating the costs of resources required for such projects and how to estimate their life-cycle costs. A major goal of both volumes is to promote an approach to project evaluation that is based upon an appreciation of the needs of society, the potential for sustainable development, and a recognition of the problems that may result from poorly conceived or poorly implemented projects and programs.

Key concepts include the following:

- **Justification of large investments**: how to determine whether future benefits justify current costs.
- **Technology-based performance functions**: creating functions with sufficient detail to explore how cost, service, capacity, and safety vary with major project options related to size, design, and technology.
- **Cost-effectiveness**: how to compare options for achieving non-monetary benefits.
- **Sustainability**: environmental, financial, economic and social aspects of sustainability.
- **Evolution of systems**: understanding how systems evolve in response to changes in needs, technologies, and financial capabilities.

Analytical methodologies can be applied to each of these concepts. However, it is critical to recognize that analysis will not necessarily determine what projects are considered, what projects are proposed, which of these projects are approved or which projects are ultimately successful.

Projects may be motivated by a vision of a greater society, by an idea for addressing a specific local problem, by the prospects of making a profit while providing a needed service, or by simple greed. Some apparently excellent projects cannot be financed, while it may be easy to fund some very questionable projects. Lackluster projects may prevent outstanding projects, and highly acclaimed projects may prevent dozens of less showy, but more effective projects. Financially successful projects may be terrible in terms of their consequences for the environment, and projects sold as being good for the environment may turn out to be overly expensive or socially unacceptable.

Project evaluation is not a hard science, as there are so many factors to consider, so many unknowns, and so many different perspectives concerning what is good or bad. Nevertheless, there is a role for analysis, if only to help people to recognize and agree upon the likely magnitude of the most important costs and benefits. Past experience, a coherent framework for analysis, and a concern for sustainability will provide a sound basis for evaluating projects, whether you are the developer, the consultant, the banker, the neighbor, the user, or the politician.

This text is published in two volumes. The first volume provides an overview of project evaluation as a multi-dimensional process aimed at creating projects that meet the needs of society. This volume emphasizes the need to consider economic, environmental and social factors along with the technological and financial matters that are crucial to the success of a project. It concludes with a chapter that considers the evolution of infrastructure-based systems and the need for more sustainable infrastructure in the coming decades.

The second volume provides in-depth coverage of the engineering economic methodologies that can be used to compare cash flows or economic costs and benefits over the life of a project. That volume presents the techniques that are used by investors, bankers, and entrepreneurs in deciding whether or not to finance projects. It also shows

how public policy can use taxes and other regulations to encourage projects that have public benefits. Both volumes present methodologies that are useful in developing and evaluating projects to deal with problems and opportunities.

As noted in the preface, the essays and case studies are all structured as stand-alone documents, so it is possible to pick and choose which ones to read, and it is possible to read them in any order.

Resource: Project Evaluation: Essays and Case Studies

Carl D. Martland