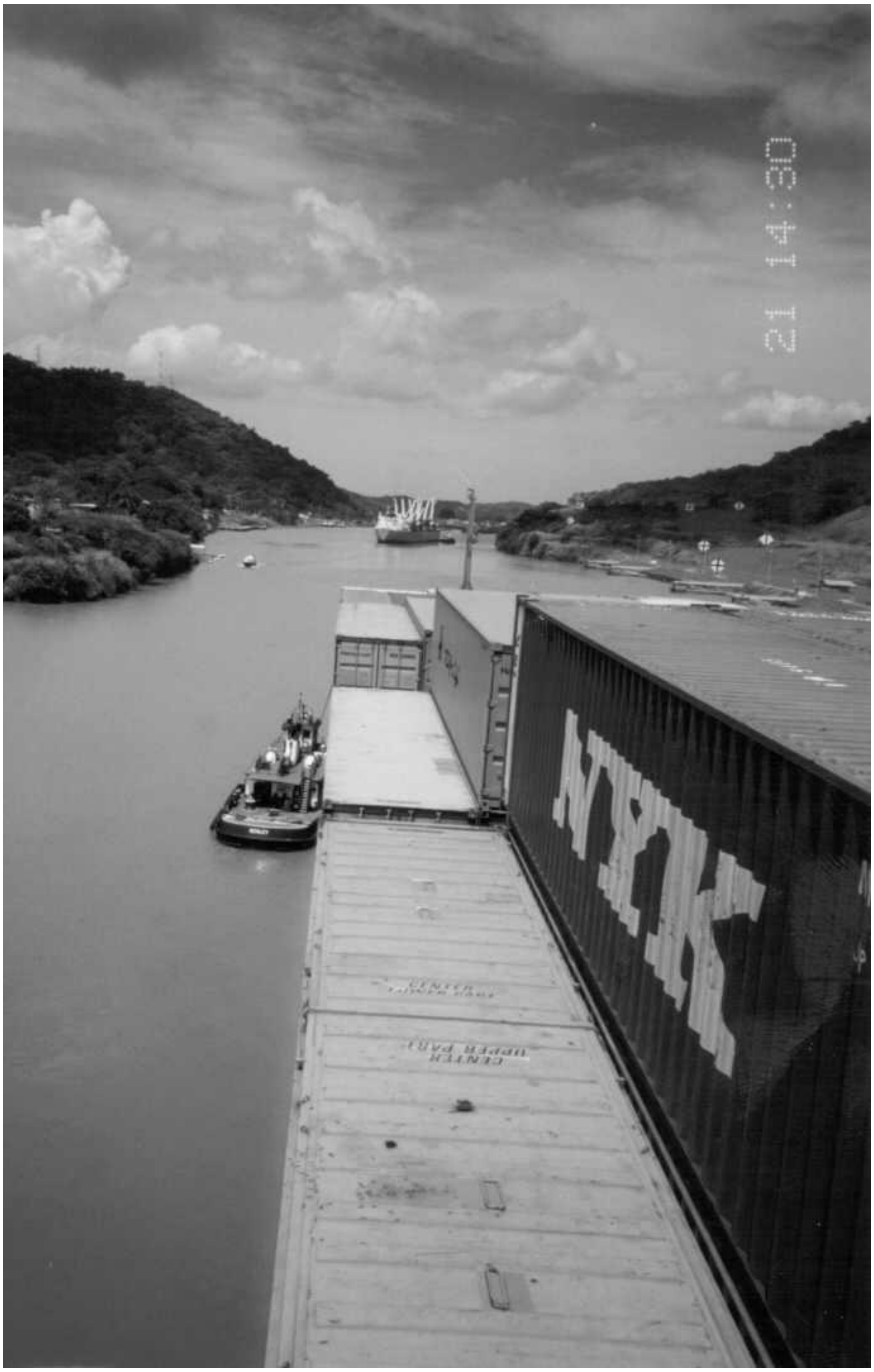
Project Evaluation: Essays and Case Studies

Volume I

Carl D. Martland



The Panama Canal
One of the greatest engineering feats of all time, the Panama Canal facilitates global trade by enabling large ships to pass easily between the Atlantic and Pacific Oceans.

Project Evaluation:
Essays and Case Studies

Volume I

Creating Infrastructure Systems that Meet the Needs of Society

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Sugar Hill, New Hampshire
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This book is based primarily upon materials prepared between 1997 and 2010 by Carl D. Martland for *1.011 Project Evaluation*, a required course within MIT's Department of Civil & Environmental Engineering that he designed, developed, and taught for many years. It is structured to be of interest to anyone interested in infrastructure systems, especially engineers, planners and managers who design, build and operate such systems. The book may also be of interest to students in planning or engineering who are interested in transportation, water resources, energy, city planning, or real estate development.

In 2012, John Wiley & Sons, Inc. published a 500-page textbook *Toward More Sustainable Infrastructure: Project Evaluation for Planners and Engineers* that was also authored by Mr. Martland and based upon the same course materials. That book, which was designed and formatted as a standard textbook for an undergraduate class, includes many more examples, hundreds of problems for students, an additional chapter on project management, and several open-ended case studies that can be used for class assignments. Instructors who purchase that textbook and assign it for their own class can obtain the textbook, a teaching guide, solutions to problems, and related power point presentations from Wiley.

Additional materials related to *1.011 Project Evaluation* can be obtained on-line from MIT's Open Courseware website, which can be accessed from MIT's homepage (www.mit.edu).

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A New Business District in Santiago, Chile

Construction of a subway system led to high-density development in a new business district located near subway stations west of the historic city center. Peaks of the Andes are barely visible in the distance.

Project Evaluation: Essays and Case Studies

Contents: Volume I

Case Studies in Volume I

Project Evaluation: Essays & Case Studies

Preface

Motivation

This book contains essays and case studies that are based upon materials that I prepared for "Project Evaluation", which I designed and taught for more than ten years as one of the required subjects in MIT's Department of Civil & Environmental Engineering. The subject was designed to fill a void in the education of civil engineering students, namely an understanding of why major infrastructure projects are undertaken, how they are structured and evaluated, and how they are financed. These topics, which naturally are of central importance to civil and environmental engineering, are related to, but certainly not central to micro-economics, the subject that was previously required for civil engineering undergrads at MIT.

Micro-economics is an interesting and challenging field, but it tends to ignore or brush quickly over some of the central issues in designing and developing infrastructure projects. Where should a project be located? When should it be built? Can it be developed in phases, so that capacity can be added only when and where it is needed? For engineers, planners, and entrepreneurs, these are critical questions. Those who want to be engineers, planners or entrepreneurs must learn how to balance current vs. future costs and benefits, and they must be able to understand and respond to the many factors that influence the pace and location of development. In particular, they must understand the time value of money, the equivalence of cash flows, and the effects of risk and inflation on discount rates and the attractiveness of projects. These are all central topics in engineering economics, but they are largely or entirely absent from the standard introduction to micro-economics. As I tell my students, economics is a bit too close to the Twilight Zone – "a dimension neither of space nor time".

A second concern with micro-economics is that many of the most interesting concepts are extremely difficult to apply without making assumptions that, to an engineer or planner or entrepreneur, seem to be simplistic or heroic or merely untenable. An engineer is likely to treat with suspicion any proposition that begins with "given a cost function" or "given a production function" or "given supply and demand curves". Where do these functions come from? How are these curves calibrated? Some economists have gone to factories and rail yards and studied the inputs and outputs actually required for the various possible means of production. More commonly, economists have relied on statistical techniques to calibrate functions that certainly appear to be very complex to the student (or to the reader of a journal article), but that in fact are a quite simple portrayal of costs or production or demand based upon analysis of what has happened in the past. For many purposes, notably many kinds of policy analysis, econometric modeling and economic theory provide useful insights, but when considering major projects, engineers, planners, and entrepreneurs are more concerned with what can be done in the future than with what was done in the past. New technologies, new designs, changes in relative costs of inputs, and many other factors will influence what will be possible or desirable to do in the future. Someone, presumably the engineers and the planners, will have to figure out what can be done and convince others that it should be done, tasks that require creativity and judgment as well as an understanding of complex systems and methodologies.

While I understand the argument that undergraduates should learn the basics of their field and that they should discipline their mind through thorough rigorous examination and understanding of a complex, intellectually stimulating subject, my personal experience suggests that students require the stimulation of real situations to truly understand the concepts that we try to teach them. Moreover, it is possible to over-emphasize methodologies and theories while doing little to encourage independent thought and initiative. Thus, in designing my class on project evaluation, I included case studies, open-ended problem sets, and a term project in which the students investigated projects of their own choosing. I had students complete some exercises from an engineering economics textbook, but I was much more interested in how well they could apply the methodologies and ideas in analyses and interpretations of realistic problems.

At this point I should add a short note on my background. As an undergrad I studied math, but lost interest as the theory deepened and the potential applications receded. As a senior and then in graduate school, I shifted to studying what was just beginning to be called "urban systems", but eventually ended up writing a thesis on rail freight system reliability. For the next 35 years, I remained on the research staff at MIT, supervising many research projects that were funded by the rail freight industry – an experience that forced me and my students to pay great attention to detail and to reality. In effect, we spent several decades working with rail researchers and field personnel to understand and improve the cost functions and production functions related to various categories of rail freight. Over this period, the rail industry transformed itself from a nearly bankrupt, over-built and under-maintained system into a thriving, streamlined system with more trains, longer and heavier trains, heavier loads, and more efficient equipment and facilities. The industry had little to spend on research, so it went to great efforts to focus that research on areas where there would be a payoff. Participating in this research proved to be an outstanding way to understand the functioning of an extremely complex, long-lived system as it was updating its infrastructure and equipment to serve new markets.

During my research career, I described much of what I did as being some sort of engineering economics. Several aspects of engineering economics were absolutely critical:

- Net present value and equivalence of cash flows: the ability to compare cash flows over long time horizons for multiple alternatives, often in an attempt to understand the potential for new technologies or operating strategies.
- Engineering-based cost and performance functions: the ability to structure detailed cost and performance functions that captured the relevant aspects of the technologies and operations that were of interest.
- Probabilistic analysis: the ability to include probabilistic features when structuring cost and service functions.
- Identification of key factors: the use of financial analysis, scenarios, and sensitivity analysis to identify the most important factors affecting a project, the use of new technology, or the choice of operating or marketing strategies.
- Approximation: appreciation of the fact that it is seldom necessary to obtain precise results in order to reach solid conclusions.
- Structuring and interpreting results: recognizing that lack of consensus regarding objectives, ambiguity related to costs and constraints, uncertainty about how systems really work, and many other factors make it unwise to accept the totally unwarranted level of precision that can be obtained from modern computational technologies.

My class on project evaluation was, like Caesar's Gaul, divided into main three parts. The first part provided an overview of project evaluation as a multi-dimensional process aimed at creating projects that meet the needs of society. The second part covered discounting, net present value, financial assessment, and other basic methodologies of engineering economics. The third part addressed issues such as risk and uncertainty, technology scanning, public-private partnerships, and the evolution of infrastructure systems over long periods of time.

Over time, the basic framework remained unchanged, but I was able to develop ever more detailed notes, additional assignments, more open-ended case studies, and more complete presentations for my undergraduate class on project evaluation. I also gave lectures on project evaluation in graduate courses at MIT in the Department Civil & Environmental Engineering, the Center for Transportation & Logistics, and the Engineering Systems Division. After retiring from my full-time appointment at MIT, I began to transform my lecture notes and other course materials into a series of essays and case studies suitable for a textbook. At the request of Jenny Welter, an editor at John Wiley & Sons, I expanded my notes by adding a great many simple examples, hundreds of problems, and new material on project management and engineering economics. In 2011, Wiley published *Toward More Sustainable Infrastructure: Project Evaluation for Planners and Engineers*, a 500-page textbook that covers the basic methods of project evaluation, provides examples attuned to infrastructure systems, and includes case studies that illustrate the breadth and excitement of project evaluation as related to infrastructure systems. Solutions to the problems, an instructor's manual, and power point presentations for each chapter are all available from Wiley. These materials can provide students and instructors with tools and concepts that they can use in understanding or teaching the need for projects, the options that are available, and the methods for evaluating and refining the options that are available.

However, a 500-page textbook is not the ideal format for presenting the concepts of project evaluation to a broader audience that includes grad students interested in infrastructure systems, mid-career engineers making the transition to management, public officials involved with infrastructure systems or anyone else with an interest in planning for, management of, or investment in infrastructure systems. I therefore decided to return to my class notes and professional papers in order to create a shorter, more focused book that would be readily available to anyone interested in infrastructure systems. Instead of a textbook with long chapters and hundreds of examples and problems, this book focuses on concepts and case studies directly related to project evaluation. It assumes the reader is familiar with supply & demand and other basic economic concepts; it does not cover project management; and it avoids going into esoteric elements of engineering economics such as equivalence relationships involving gradients or geometric sequences. Nevertheless, most of material in this book is very similar to what is in the textbook, because both books draw upon the same notes, case studies, technical papers, and presentations that I developed while teaching my class on project evaluation between 1997 and 2009.

The material includes two categories of documents, namely essays and case studies. Those who wish to gain a broad conceptual framework for understanding project evaluation in the context of infrastructure systems can read the essays; those who wish more detail on methodologies in the context of specific projects can concentrate on the case studies. Each essay and each case study is a stand-alone document that be read without being distracted by references to definitions or methods developed in prior or subsequent chapters. *Project Evaluation: Essays and Case Studies* should therefore be useful to practitioners and anyone with a general interest in project evaluation or infrastructure, even though it may be less appealing to a professor hoping to find a multitude of simple examples and a great many problems for his students to solve.

Although this book does not include sample problems and problem sets, such materials can be found under "1.011 Project Evaluation" as part of MIT's Open Courseware website at www.MIT.edu or directly from:

http://dspace.mit.edu/bitstream/handle/1721.1/75001/1-011-spring-2005/contents/index.htm?sequence=5

This web site provides the syllabus, reading lists, assignments, quizzes and other class materials for several different versions of the class. It also includes student presentations for a half dozen major projects, each of which would be interesting to a general reader of this book. The URL shown above is for the 2005 version of "Project Evaluation", which is the most complete version on Open Courseware for the years when I alone was responsible for this subject.

Structure of *Project Evaluation Essays and Case Studies*

Project Evaluation: Essays and Case Studies is published in two stand-along 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. The essays and case studies in this volume provide a framework for understanding and evaluating projects, taking into account not only the financial and economic issues, but also social and environmental factors. The essays in this volume emphasize that analysis will not necessarily determine what projects are considered, what projects are proposed, what projects are approved or what 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. Case studies in Volume I are mostly based upon actual infrastructure projects.

Volume II examines the equivalence relationships that can be used to compare cash flows or economic costs and benefits over the life of a project. It covers the concepts and methodologies that can be used by investors, bankers, and entrepreneurs in deciding whether or not to finance projects, and it shows how public policy can use taxes and other regulations to encourage projects that have public benefits. Most of the case studies in Volume II present hypothetical situations that illustrate how various methodologies can be used in project evaluation.

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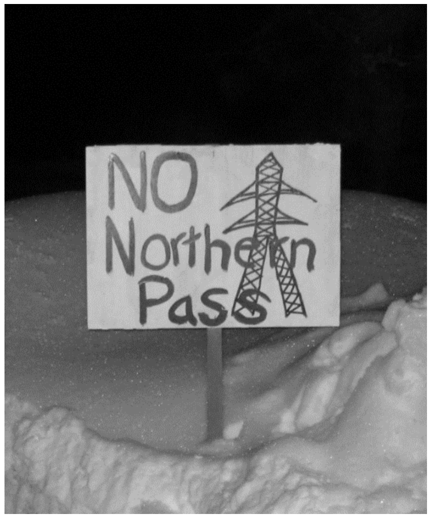
High Voltage DC Transmission Lines in Quebec



Protesting Extension of HVDC Lines Across New Hampshire

The Province of Quebec has invested heavily in hydropower that Hydro Quebec, a crown corporation, transmits electricity to New England and New York via steel lattice towers that are typically 90 feet tall or taller. Northern Pass, a proposal to construct nearly 200 miles of such lines across New Hampshire, is strongly resisted by conservation groups and the public, who would prefer the line to be buried in order to avoid destroying the natural beauty that is beloved by residents, attracts tourists, and lures retirees and second home owners to the North Country.

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.

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[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.

Basic Economic Concepts

"The quality of a nation's infrastructure is a critical index of its economic vitality. Reliable transportation, clean water, and safe disposal of wastes are basic elements of a civilized society and a productive economy. Their absence or failure introduces an intolerable dimension of risk and hardship to everyday life, and a major obstacle to growth and competitiveness."[1]

Introduction

This essay introduces various economic concepts that are useful in understanding infrastructure systems and in identifying and evaluating potential projects for improving their performance. The chapter begins with a discussion of how **equilibrium prices** result from the interaction of **supply and demand**. If prices are high, say for office space or for energy, then a great deal of investment in new buildings or oil drilling or wind power is justifiable. If too many buildings are built or if too much oil is available on the world market, then prices fall and investments based upon continuing high prices may well fail. The success or failure of any major project will depend in part upon the future interactions between supply and demand.

Costs, prices, and values are distinct concepts that should not be confused. The cost of providing a service or of manufacturing a product depends upon such things as resource requirements, capacity requirements, and unit costs associated with operations. While owners surely desire that prices be higher than costs, prices are usually determined by market forces that may have little or no relationship to cost. The value of a product or a service is something that can only be determined by potential purchasers: if they perceive the value of a product or service to be higher than the price, then they will go ahead and make the purchase. The difference between what they were willing to pay and what they actually paid is an economic benefit known as **consumer surplus**, which is in fact an economic benefit even though it does not result in any revenue to the supplier. Large infrastructure projects are often justified in part by increases in consumer surplus, so this is an important concept for evaluating such projects.

From an economic perspective, a major goal of any project will be to increase **productivity**, which is defined as the ratio of system output to system input. If productivity improves, then more output can be obtained using the same or fewer resources, resulting in an overall benefit for society. If a company is able to produce more without increasing its labor force, then it may be able to afford to pay higher wages to its employees. Companies and agencies that manage infrastructure will continually be seeking ways to make more productive uses of their resources, and productivity improvement motivates many infrastructure projects and programs. In most infrastructure systems, there are **economies of scale, scope or density** that allow larger, more complex systems to offer more benefits at a lower cost.

Lower cost would seem to be a clear benefit to society, but project evaluation must consider who will capture the benefits of lower cost, the supplier or the customers? The answer to this question depends upon the extent of competition. If there are many potential suppliers, then there will be competition for customers, and prices will fall to marginal costs (**marginal cost pricing**) and customers will benefit from any productivity improvements. However, if a single supplier has no competition or very limited competition, then it will be able to charge prices that are well above marginal costs. The threat of **monopoly pricing** is therefore present whenever there are strong economies of scale. To achieve public benefits from scale economies related to essential infrastructure, it may be necessary to have public ownership or some sort of **price regulation**.

There are multiple reasons why infrastructure performance and major infrastructure projects will always be of interest to the public:

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[1] National Council on Public Works Improvement, **Fragile Foundations: a Report on America's Public Works**, Final Report to the President and Congress, February 1988, p. 1

- First, the public uses the infrastructure, and the performance of the infrastructure affects everyone's daily life.
- Second, much of the public infrastructure is owned or regulated by public agencies, so that there is a direct public interest in managing and investing in that infrastructure.
- Third, infrastructure projects are large projects with long-lasting impacts on society and the environment, and the public has a justifiable interest in questioning whether these impacts are positive or negative and whether the costs and benefits of a major project are equitably shared.
- Fourth, investment in infrastructure projects can provide a boost to the region in terms of jobs, income, and economic growth through what is called the **multiplier effect**.

Infrastructure needs depend in part upon the economic forces that drive regional, national, and international development. Where goods are produced depends in part upon where raw materials can be found, where it is most efficient to produce the goods, where labor and other resources are cheapest, and the cost of transportation. As transportation costs decline, because of improvements in technology and expansions of transportation infrastructure, distance ceases to be an impediment to consolidation of agriculture, manufacturing, mining, and other industrial activities. Cheap transportation has enabled the rise of a global economy, and regions in one country now compete with regions in other countries for all sorts of economic activities. Two concepts that are directly relevant to understanding the global economy are **spatial price equilibrium** and **comparative advantage.** As patterns of trade and production shift, the needs for industrial facilities and transportation infrastructure also shift. In the less developed parts of the world, investments in infrastructure may be required for the economic growth. In the developed parts of the world, existing infrastructure that was designed for the economy of the 19th or 20th centuries may need to be redeveloped or replaced by infrastructure relevant to the 21st, with greater emphasis on major ports and continental distribution systems and less emphasis on access to local production facilities.

Project evaluation requires consideration of broad economic issues such as globalization, the need for regulatory policy, corporate decision-making, and the importance of regional economic impacts. However, it is also worth considering the perspective of the individuals who ultimately will be making the decisions that determine which types of infrastructure are used, how much revenue is gained, and whether or not infrastructure projects prove to be successful. Individuals decide such things as how much living space they need, whether to live in the city or a suburb, whether or not to water the lawn on a regular basis, whether to drive or take the bus to work, whether to switch from oil to natural gas for home heating, and where to go on vacation. The concept of **utility** provides a framework that can be used to understand how these decisions are made. The basic idea is that individuals are assumed to make decisions that maximize their utility based upon personal constraints related to time and money.

Supply, Demand, Equilibrium

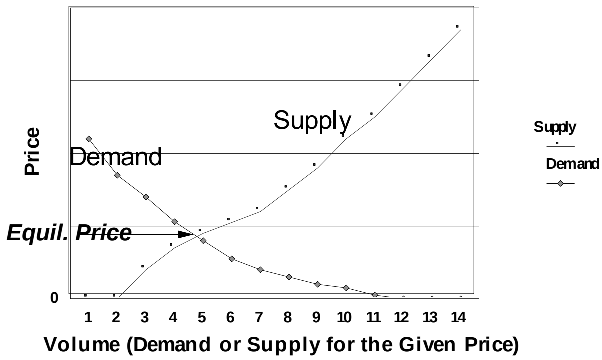
<u>Overview</u>

Supply, demand, and equilibrium are central issues in economics. At the most basic level, both supply and demand are described as functions of price, and the **equilibrium price** is the price at which supply equals demand. The **supply function** shows the quantity of goods or services that will be produced for each price. Under normal circumstances, the supply of goods and services would be expected to increase as the price increases. If the price is higher, then existing suppliers will be willing to produce more, and new suppliers may be enticed to enter the market. The **demand function** shows the quantity of goods or services that will be purchased for each price. Under normal circumstances, the demand will decline as the price increases. Some people may be willing to pay a high price, but more people will be willing to pay when the price is lowered.

The interaction between supply and demand can conveniently be expressed in a chart as portrayed in Figure 1. Note the convention that price is shown on the y-axis, although that is assumed to be the independent variable, while the volume or quantity of supply and demand are shown on the x-axis. The point at which the supply and demand functions intersect is the equilibrium price. What is most important to understand is that this equilibrium price reflects both supply and demand: under competitive market conditions, prices will adjust to changes in supply and demand, and there will be a tendency for supply to match demand.

Figure 1 Supply, Demand Equilibrium

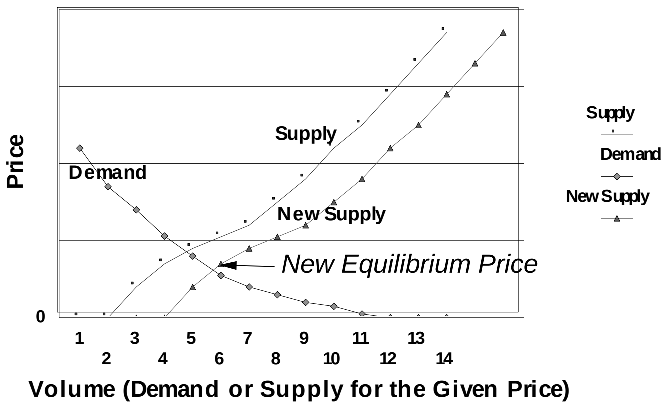
Prices are determined by the interaction of supply and demand



Over time, factors that affect both supply and demand are subject to change. First consider changes in supply. Investing in new technologies or in more efficient production facilities or simply adopting better management techniques may make it possible for suppliers to offer greater quantities for any given price. Graphically, this results in a shift in the supply curve to the right and leads to a new – lower – equilibrium price, as shown in Figure 2. Note that the demand curve has not changed at all: with the lower prices, people are willing to buy more, which is what is described by the demand curve.

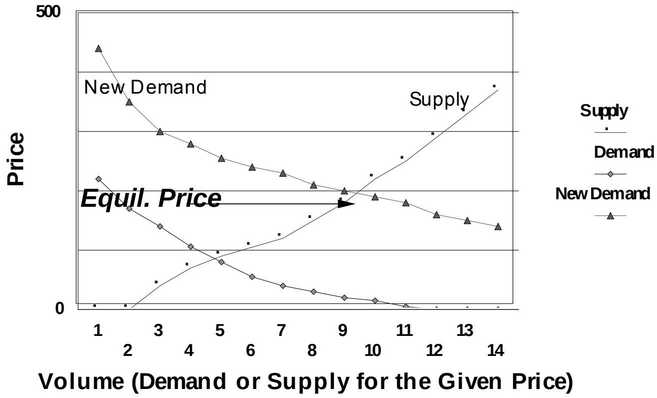
Figure 2 A New Supply Curve

Investment may allow suppliers to be more productive and offer lower prices, resulting in a shift in the supply curve and a lower equilibrium price (resulting from a movement along the demand curve)



The demand curve may also change (Figure 3). For example, growth in population or increases in family income may result in an increase in cars purchased, attendance at movie theatres, or use of air transportation. These changes appear on the graph as an upward shift in the demand curve: at each price level, a greater quantity of goods and services is purchased or used.

Figure 3 A New Demand Curve
Population growth, advertising, higher incomes or other factors may cause an increase in demand and a higher equilibrium price.



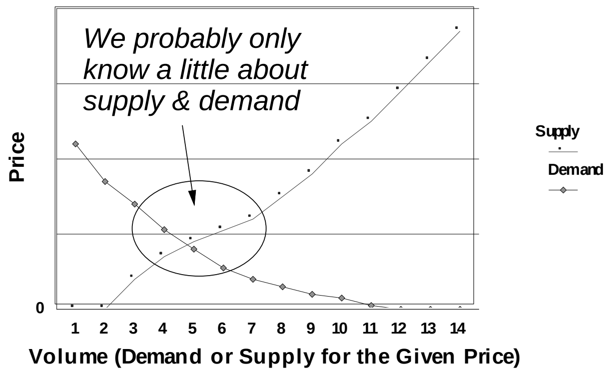
If demand increases, then prices will rise; if demand declines, then prices will fall. How much prices rise or fall will depend upon the shapes of the supply and demand curves. How quickly prices rise or fall will also depend upon the nature of the goods and services being sold. Outside a sold-out baseball stadium, the prices that scalpers charge for tickets will react within minutes to changes in demand. Achieving an equilibrium in the prices of new homes is something that may take years, as evidenced by the steady decline in home prices that began in 2007 and continued for several years thereafter because of what has been called "The Great Recession." Adjusting transportation networks to changes in oil prices or new technologies is a process that takes decades – and may never reach equilibrium, because only a small portion of the transportation network can ever be changed within just a few years.

In many circumstances, changes in demand result not in a change in price, but in poor service, congestion or long lines as too many people try to buy something or to use something at the same time. The time spent in line can be viewed as part of the price of the service that is being sold: some people will come with an intent to buy, but depart as soon as they see the line.

Over time, suppliers will react to changes in demand by adjusting their levels of production. New companies may emerge in response to increases in demand; companies may go out of business in response to decreases in demand.

It is possible to spend a lot of time trying to understand the supply and demand curves, and there are some ingenious methods for estimating these curves based upon past experience. However, it is important to retain some humility, for we probably only know a little about how supply and demand vary within a fairly small range of prices and existing conditions (Figure 4). When new projects are being considered, it is possible that the quantity or quality of services provided will be far different than what is currently available. Special studies can be undertaken to try to estimate the effects of the new projects on demand, but such studies will never be exact.

Figure 4 The interaction between supply and demand may not be readily understood, especially if the factors affecting supply and demand have been fairly stable for a long time



Consumer Surplus

Given the shape of the demand curve, it is clear that the equilibrium price is lower than the price that many would be willing to pay. The difference between what someone is willing to pay and the equilibrium price is called **consumer surplus**. For each individual:

(Eq. 1) Consumer Surplus = (Willingness-to-pay) – (Equilibrium Price)

Consumer surplus is greatest for those willing to pay the highest prices. For someone willing to pay only the actual price and not a penny more, the consumer surplus is zero. The total consumer surplus in principle could be obtained by summing the surpluses for everyone using a product or service. In practice, this is infeasible, as data is collected and decisions are made based upon actual prices. Unless special studies are undertaken, little is known about how much more people would be willing to pay for things that they now buy or for services that they now use. For this reason, it is easier to focus on the changes in consumer surplus that may result from changes in equilibrium prices.

Consider the change in supply illustrated above in Figure 2. The shift in the supply curve increased consumer surplus by a) lowering the price for those who previously were willing to pay a higher price and b) allowing more people to purchase the product. The increase in consumer surplus can be estimated just by looking at prices and volumes before and after the change in supply:

(Eq. 2) Increase in Consumer Surplus = $V_0 (P_0 - P_1) + ½ (V_1 - V_0) (P_0 - P_1)$

The first term in this equation is the benefit to existing users from the reduction in price, while the second term represents the benefits gained by new users. The full decline in price is not a benefit for new users, since they were unwilling to pay the old price. If the relevant portion of the demand curve is assumed to be a straight line, then the consumer surplus for the new users will be the area of a triangle whose base B is the difference in volume and whose height H is the difference in price, and whose area is ½ BH. In effect, this assumption – sometimes called the **"rule of ½"** - provides a simple way to estimate the area under the demand curve without needing to estimate an equation for that curve.

Note that consumer surplus is an economic rather than a financial concept. Price is a financial measure, as is manufacturing cost; these are things that can be measured in dollars and cents and these are things that can and will be recorded in check books and accounting systems. Consumer surplus is not related to any such accounting, but it is still an important matter for evaluating the economic impact of projects. There is a public benefit resulting from projects that increase consumer surplus, because people will still have the money that they otherwise would have been willing to pay for the product or the service. They can save that money or use it to buy something else. Either way, there is a benefit for the individuals and for the local economy. Thus, change in consumer surplus, though not a direct concern for the private sector or for investors, is an important consideration in evaluating the public economic impacts of proposed infrastructure projects.

Elasticity of Demand

It is possible, but difficult, to obtain the detailed information needed to plot supply and demand, so a more abstract approach is often used. Consultants or marketing managers may use past experience in trying to answers questions such as "How much will demand change for a given change in price?" or "Will total revenue go up, down, or stay the same if the price is changed?"

These questions can be answered by using the concept of **elasticity of demand**, which is a measure of how sensitive demand is to changes in price. Elasticity of demand is defined as the negative of the derivative of the quantity demanded Q with respect to price P.

(Eq. 3) Elasticity of demand = - dQ/dP

This measure may also be referred to as **price elasticity**. The minus sign in this equation is conventionally used because the quantity demanded is expected to vary inversely with the price that is charged. Elasticity of demand can also be estimated by looking at the change in demand that occurs after a change in price:

(Eq. 4) Elasticity of demand = $-((Q_1-Q_0)/Q_0)/((P_1-P_0)/P_0) = -((Q_1-Q_0)/(P_1-P_0))(P_0/Q_0)$

In this equation, the changes in quantity and price are both normalized by dividing by their values before the price change. The equation therefore can be interpreted as the percentage change in quantity divided by the percentage change in price.

To understand the importance of price elasticity, consider the two effects of a price decrease from P_0 to P_1 on total revenue PQ. Existing customers will pay less, because the price is lowered, and there will some loss of revenue:

(Eq. 5) Reduced revenue from original customers = $Q_0\,(P_0-P_1)$

However, the lower price will attract new customers, so the quantity demanded will increase from Q_0 to Q_1, providing some additional revenue:

(Eq. 6) Additional revenue from new customers = $P_1\,(Q_1 - Q_0)$

If elasticity is greater is greater than one, then the percentage increase in Q will be greater than the percentage decrease in P, and the added revenue from Eq. 6 will be greater than the loss of revenue from Eq. 5. If this is the case, demand is said to be "elastic", because there is a large response to changes in price. If elasticity is less than one, then the opposite is true: total revenue will decrease if prices are lowered, as the added revenue from new customers will be insufficient to offset the loss of revenue from existing customers. When elasticity of demand equals one, there will be no change in total revenue PQ, as the effect the change in price will be exactly offset by the change in demand.

Price elasticity is an important factor in infrastructure systems, because these systems tend to have high fixed costs and low variable costs. Maximizing revenue may therefore seem to be a reasonable goal, since the greatest obstacle to making a profit is having enough revenue to cover the fixed costs of the system. During the early portion of the 21st century, tremendous investments in satellite-based communications were justified in part upon the expectation that creating a very high-capacity system with very low prices would lead to extraordinary increases in demand – which is exactly what happened as technological advances lowered the costs of email, cell phones, and wireless access to the internet.

In the short run, demand tends to be more inelastic than in the long run. For example, when the price of oil rose dramatically in 2007 and 2008, people initially had to pay the higher price and perhaps cut back on non-essential driving. Over a period of a year or two, however, people were able to adjust in part by buying more fuel efficient cars and in part by figuring out how to combine errands, share rides, and use public transportation. Over a period of a decade or longer, the automobile companies can develop cars that use alternative energy sources, allowing people to drive more while using less oil.

Elasticity of demand is an important concept to keep in mind when evaluating infrastructure projects, because demand forecasts will drive decisions related to the size and therefore the cost and capacity of infrastructure. Forecasts based upon continuation of low prices or free access will lead to extravagant statements of infrastructure needs. Such has long been the case with urban road networks: with the exception of a few toll roads, there is no charge for using highways, and there should be no surprise that these roads have become so congested. Where tolls have been introduced, as in London and Singapore, it has proved possible to reduce traffic volumes and thereby limit congestion to reasonable levels. Water supply is another area where unrealistically low prices have in many locations led to unnecessarily high rates of consumption; future "needs" for water should take into consideration the effect of more rational pricing on consumption.

Based upon the concepts of equilibrium prices and demand elasticity, it is apparent that future demand for infrastructure will depend to a greater or lesser extent upon the prices that are charged. If demand is elastic, then pricing could have a dramatic effect on demand, and raising prices could be viewed as a way to reduce or avoid investments that increase infrastructure capacity. If demand is highly inelastic, then pricing will probably not be an effective means of limiting demand, and failure to expand capacity could lead to extremely high equilibrium prices, extremely poor service, or a need for regulating use or access. Elasticity of demand is therefore an important factor both in pricing infrastructure services and in forecasting demand for infrastructure. The next section continues the discussion of pricing in the context of the degree of competition among suppliers.

Pricing

This section introduces two markedly different pricing regimes: competitive markets and monopolistic pricing. In a competitive market, there are many suppliers and many potential customers, none of whom have the power to set prices. Instead, as described above, prices reflect an equilibrium between supply and demand. Not all markets are competitive, and it is possible that geography, politics, or economic factors encourage the development of companies or agencies that have a monopoly for particular goods or services. In the absence of regulation, a monopoly can set prices and customers have little power. Monopolies are not necessarily evil, because there are many situations where a single large supplier can produce goods or services at the lowest possible cost. Moreover, the danger of monopolistic pricing can be controlled by government regulation, so that the benefits of low cost production are passed on to society and not simply captured as excessive profits by the owners of the monopoly.

Marginal Cost Pricing in a Competitive Environment

In a competitive environment, prices will fall to marginal cost. A competitive environment is one in which many suppliers all have access to the same or similar technologies, and they are serving customers who are able to purchase goods or services from any of the suppliers. Under these conditions, a supplier who tries to raise prices above marginal costs will have a problem: another supplier will be willing to offer a slightly lower price and thereby capture the business. So long as the price is above the marginal cost, each sale will give the supplier some **contribution to overhead and profit**. Under perfect competition, no supplier has any pricing power, and prices are determined by the cost structure, the available technologies, and the level of demand.

Marginal cost pricing is efficient in the sense that prices reflect the actual cost of the product or the service. All of those who purchase the product or service are in fact willing to pay – and do pay – the marginal cost of production. While others may desire the product or service, they are unwilling to pay enough to make it worthwhile to any of the suppliers. Any supplier who can provide the product or service at a lower price is free to enter the market and make a profit by selling at or somewhat less than the prevailing price.

Situations where prices differ from marginal cost are likely to be inefficient in economic terms. If prices are too low, then demand will be too high and some users will be incurring costs that they would not be willing to pay for. If prices are too high, then many who would have been willing to pay a reasonable amount for the service will be unable to afford to make a purchase.

A major difficulty with marginal cost pricing arises in situations where marginal costs drop below average costs, as is commonly the case with infrastructure systems. In such situations, marginal cost pricing will not provide sufficient revenue to cover costs, and all suppliers will face bankruptcy. Technological advances and increasingly efficient production may help some suppliers stave off bankruptcy, but only the most efficient suppliers will be able to survive. In these situations, some kind of government regulation or subsidies may be needed to enable suppliers to remain in business. Regulation could take the form of limiting entry into the market or establishing prices at a level that allows suppliers to make a profit. Examples of governmental actions that limit entry include the following:

- Issuing taxi medallions in an attempt to limit the number of taxis to what will be efficiently utilized.
- Requiring railroads to seek regulatory approval before constructing new lines.
- Creating public utilities for communications or energy services.

Generally, when entry is limited, prices must be regulated to ensure that prices are reasonable.

Economies of Scale, Scope, and Density

A competitive market requires multiple suppliers who are free to determine whether or not to enter the market based upon the prevailing prices. If there are many companies, and it is easy to enter and exit the market, then supply and demand can quickly approach an equilibrium. However, the equilibrating process will be hampered if there are barriers to entry, such as the need to make large investments in order to be able to compete. For infrastructure-based systems, this is certainly an issue, as these systems by definition require substantial investments, and it will take time and effort to construct a competing system. Moreover, there are very likely to be economies in creating large facilities that can serve multiple purposes for many different users. Having competition among a great many – or even a few – smaller companies may be less efficient that having a single supplier. Larger systems may have three types of advantages over smaller systems: economies of scale, scope, and density.

Economies of scale exist when an increase in the size of the system results in reductions in cost. If C(Q) is the total cost of providing infrastructure adequate for usage Q, then there are economies of scale if:

(Eq. 7) $$C(Q_1 + Q_2) < C(Q_1) + C(Q_2)$$

For transportation, water resources, electric power grids, and other network-based systems, there will often be economies of scale because:

- A single management team can manage a larger system using the same basic information technology.
- The same advertising can be used for a wider audience.
- A larger network allows a company to provide single-company service to more customers, and direct service may be cheaper than service that requires cooperation among multiple suppliers.
- A larger network provides direct links between more locations, which in transportation or communication systems can be a major benefit for potential customers.
- Consolidated maintenance facilities can serve a wider area.
- The costs of energy and materials can be reduced because a larger company can negotiate lower prices from suppliers.

Economies of scope exist when it is more efficient to use facilities for two or more types of service than it is to use them for a single service. If $C(Q_i,S_i)$ is the cost of serving Q_i customers of type S_i and $C(Q_1,S_1,Q_2,S_2)$ is the cost of serving two groups of customers, then there are economies of scope if:

(Eq. 8) $$C(Q_1,S_1,Q_2,S_2) < C(Q_1,S_1) + C(Q_2,S_2)$$

A situation where there are clearly economies of scope would include highways, which serve commuters and intercity travelers moving in automobiles or buses along with local trucking and intercity trucking. Another situation would be a dam that is constructed for flood control that also can be used to generate electricity and support irrigation. If there are potential economies of scope, then there will be advantages to society from building joint facilities.

On the other hand, there are situations where it does not make sense to have a single facility for multiple services. Because of potential safety problems, pedestrians and cyclists are not allowed on high-speed, limited access highways. High-speed passenger trains cannot operate on tracks designed for freight trains, because high-speed trains cannot be safely operated on routes with sharp curves and frequent grade crossings. Swimming is not allowed in reservoirs, because of possible public health problems.

Economies of density exist when average costs decline as a result of adding more volume to an existing system:

(Eq. 9) $$C(Q_1 + Q_2) / (Q_1 + Q_2) < C(Q_1)/ Q_1$$

If applied to a single facility, economies of density would exist wherever scale economies exist. The distinction, however, between economies of scale and economies of density is very critical in transportation and other networks where there are many facilities and an extensive route structure. Costs in these networks relate to both the links and nodes of the system, and there are two major strategies for capturing more business, namely expanding the network or adding more volume to the existing network. In network systems, economies of scale refer to situations in which the network expands in proportion to the increase in demand, whereas economies of density refer to the effects of adding more traffic to existing facilities.

Even if there are no economies of scale, there could be strong economies of density. Much of the investment in transportation systems has been attempting to capture economies of density, e.g. by concentrating more cars on existing roads and more flights at existing airports. Most transport networks have strong economies of density up to the point where added traffic causes extreme congestion.

The distinction between economies of scale and economies of density can also be seen in restaurants and retail sales. Large retail outlets, such as Staples or Home Depot, are able to achieve lower fixed costs per unit of sales by having very large efficient buildings with managers and employees who can be more specialized and also more productive than they would be at smaller stores; with a larger work force, it is easier to adjust up or down for peak periods or slack periods. Big box retail stores therefore capture economies of density.

Fast food outlets such as McDonalds and Burger King, which have thousands of restaurants all over the country and around the world, are able to achieve scale economies. While they have some facilities that are larger than others, they have vast numbers of similar restaurants that benefit from brand recognition, common procurement, common design, and standard management. These restaurants have lower unit costs than the individual restaurants and smaller chains that they compete with, and they use extensive marketing to convince us that their food is not just cheaper, but just as tasty. People know what to expect when they walk into one of these restaurants, and therefore people are likely to go to these restaurants not just when they are near home, but also when traveling or vacationing in another state or another country. These companies clearly profit from scale economies.

Monopoly Pricing

Where there are possibilities for economies of scale, scope, and density, there can be strong forces leading to supply-side consolidation. The motivation initially is to save costs or to expand markets, but if competition is reduced, then it could be that a single company achieves monopoly pricing power. If demand is inelastic, this can lead to extremely high prices, not to mention extremely high profits.

If there are economies related to size, a larger company can always underprice smaller companies and still make a profit. Hence, they can drive competitors out of business, then, when no one else is left, they may have the opportunity to raise prices so as to maximize their profits. Naturally, the public and public officials are against monopolistic pricing, but they also are likely to favor lower prices. Therefore, in situations where there are strong economies of scale, public agencies will often allow one or a few companies to exist, but regulate their prices and perhaps their services. Examples of publicly owned or regulated monopolies include most transit systems in the United States, most agencies that provide water and sewage treatment, and most public utilities.

Productivity

Productivity, a classical consideration in economics, is defined as output divided by input. Productivity can be increased either by increasing the outputs obtained from the same level of inputs or by reducing the inputs required to obtain the same level of output. Improving productivity allows a company, an industry or a society to produce more and/or to consume fewer resources. Improving productivity therefore is generally viewed by most everyone as an important goal. Officials in the private sector believe that productivity improvements will lead to higher profits, while those in the public sector believe that higher productivity will lead to higher income for workers, lower prices for consumers, and better opportunities for growth in the economy. Achieving higher productivity motivates many infrastructure projects.

Measuring productivity is complicated by the fact that there are usually multiple types of outputs and inputs. Thus, to get the ratio of outputs to inputs it is necessary to have some kind of weighting system for measuring both outputs and inputs. For example, in looking at the productivity of the air transportation system, output cannot simply be measured as the number of passengers or the number of passenger-miles; it is necessary to consider the differences among short- and long-distance flights for business and non-business travelers. With water supply systems, it is necessary to distinguish among water supplies for residential, industrial, and agricultural users. With electricity companies, it is necessary to consider peak loads vs. off-peak loads. In all of these systems, inputs will include many factors that can be summarized under broad headings of labor, capital, land, materials, and energy.

One simplifying approach is just to consider a single measure of output and a single factor of production, leading to measures such as the total number of air passenger trips per airline employee or the amount of electricity generated per unit of investment. These single-factor measures tend to be somewhat arbitrary, as production really does require multiple factors, but such measures may be reasonable for measuring productivity changes for a single, fairly stable operation.

Another possible approach is to weigh outputs by their prices and to weigh inputs by their costs, perhaps using information from a base year for both prices and cost. If this is done, then the aggregate measure of output will be something close to "total revenue" and the aggregate measure of input will be something close to "total cost", and the ratio of output to input will be the ratio of revenue to cost. A variant of this approach is to assume that prices reflect marginal cost, in which case price can be assumed to be a measure of cost. Since price information is more readily available than cost information, this can be a useful assumption. If there is a meaningful measure of output, then the inverse of the price per unit may be a reasonable measure of productivity. Over time, changes in the price per unit can therefore be viewed as an indicator of changes in productivity.

For example, tremendous gains in productivity have been achieved in freight transportation over the past 200 years. Table 1 shows three factors that contribute to freight productivity: the cost per mile for construction, the tons carried per vehicle, and the miles traveled per day. The most commonly used measure of output in freight transportation is the ton-mile, which is one ton carried one mile. Typical costs and prices are shown in this table for two periods, the early 19th century and the early 21st century. The costs are current costs, unadjusted for inflation.

Before 1800, there were only two types of freight transportation that were generally available: wagons moving over bad roads and somewhat larger wagons moving over improved roads, which were usually limited to a few turnpikes radiating out from major cities. At that time, a turnpike was often just a dirt road that was maintained to allow slightly heavier vehicles to travel the straightest possible path between two towns. When using the turnpike, it was possible to use a larger wagon and to go a little faster simply because the road was smoother and a bit wider. Even with the turnpikes, transport was slow and expensive, and typical prices exceeded 15 cents per ton-mile.

Table 1 Increasing the Productivity of Freight Transportation

Technology	Cost per Mile to Construct	Tons/vehicle	Miles/day	Ton-miles per vehicle day	Typical Prices (cents/ ton-mile
Early 19th Century					
Rough road	$1-2,000	1 per wagon	12	12	20 to 40
Turnpike	$5-10,000	1.5 per wagon	18	27	15 to 20
Canal	>$20,000	10 to 100 per canal boat	20 to 30	200 to 3,000	5 to 10
Railroad	$15-50,000	500 per train	200	100,000 per train	3 to 5
Early 21st Century					
Arterial roads	$1-5 million	10 per truck	100	1000	10 to 50
Interstate Highway	$5-100 million	20 per trailer	500	10,000	10 to 15
Heavy-haul railroad	$1-5 million	5-15,000 per train	500	5 million per train	2
Inland waterway	Highly variable	1500 per barge; up to 40 barges per tow	50-200	6 million per tow	1

Rivers and canals allowed larger loads and longer daily hauls, as it is much easier to pull a canal boat along a river than to drive a horse and wagon up and down the hills. In the early 19th century, canals were built for upwards of $20,000 per mile; the expense was justified by the increased productivity for the freight carriers, and typical freight rates fell below ten cents per ton-mile. Canals were limited by geography, so rail technology had a great advantage as soon as it became available. Even with only 500 tons per train, a railroad allowed much more productive freight operations than was possible with small canal boats, and typical freight prices dropped below five cents per ton-mile. Technological improvements continued throughout the 19th and 20th centuries, so that today, the prices for freight transportation are actually lower than they were 200 years ago. The lowest prices are achieved for fully loaded vehicles traveling at the maximum speed on the main routes – tractor/trailer combination trucks on the Interstate Highway, heavy coal trains on high density, well-maintained rail lines (Figure 5), and tows of 40 barges moving along the major rivers.

This example used the ton-mile as a simple measure of output for freight transportation, even though the costs and benefits of transporting different commodities different distances can vary widely. For example, it is easier to move coal in single shipments of 10,000 tons than it is to move 10,000 tons of general merchandise as 200 separate shipments. Nevertheless, even though the ton-mile is far from a perfect measure of rail output, the cost/ton-mile remains useful in highlighting the dramatic productivity improvements that have been achieved in freight transportation.

Perceived productivity problems often suggest the types of projects that need to be undertaken:

- Peak demands may cause delays at bottlenecks in transportation or systems (so consider investing to relieve bottlenecks).
- Engineering constraints, such as weight limits on bridges or band-width limitations in communications networks, may restrict the usage of the system (so consider investing to increase the ability of the infrastructure to handle larger or heavier loads or higher volumes of usage).
- Lack of communication and control may inhibit efficient use of resources (so consider investing in communications and control systems).
- Facilities that were designed and built many years ago may no longer match what is needed today or in the future (so consider rehabilitating or expanding or redesigning facilities or networks).

Figure 5: Coal trains carrying up to 15,000 tons of coal operate on narrow rights of way through difficult territory like this canyon in Colorado. A double-track route like this can handle more than 100 million tons of freight per year – plus a pair of 79 mph passenger trains. The interstate highway is visible on the other side of the river. To minimize its footprint, it was double-decked for a portion of the route. There is also a bike path beneath the highway.

Photo: S.J. Martland 2000.

Measuring and Improving the Economy

Infrastructure projects have impacts that go well beyond the financial affairs of owners and users. Infrastructure allows and supports other economic activity, and the greatest benefits of investment in infrastructure may be the new opportunities made available to society. In evaluating large infrastructure projects, two types of economic impacts are commonly considered:

- The short-term boost to the local economy resulting from the planning and construction of the project.
- The long-term impact of the project on the region's economy once the project is completed, including the benefits to users of the new infrastructure as well as the permanent jobs directly linked to the project.

Constructing a light-rail line to the airport in order to relieve highway congestion and improve access does much more than provide jobs for operating the trains and maintaining the tracks; it also saves time for air travelers, airport employees, commuters who use the new line, and highway commuters who experience less congestion, as well as creating opportunities for developing real estate near the light-rail stations.

Short Term Economic Impacts: the Multiplier Effect of New Investment

The design and construction of a major project boosts the economy, because of what is known as the multiplier effect. Consider the construction of a new building in a city. Much of the investment cost will be made up of wages and salaries paid to local construction workers and payments to local merchants for materials and services. These workers may save some of their wages, but they are likely to spend most of it; likewise, the local suppliers will spend most of what they receive. The proportion of the new income that they consume is called the **marginal propensity to consume**.

Let's say that the construction of the building resulted in wage payments of $1 million to local workers and companies. This $1 million will in itself be an addition to the regional economy, but that is just part of the story. If the marginal propensity to consume is 0.5, then workers and companies will spend another $0.5 million – which will be another addition to the local economy. And that $0.5 million will go to other workers and companies who will save some and spend some. If they also save half and spend the rest, then there will be another $0.25 million added to the regional economy. And some of that money will also be spent. If half of the money is saved at each step, then the total addition to the regional economy will be $1 million (1 + 0.5 +0.25 + 0.125 + …) which will converge to $2 million dollars. In this case, the multiplier is 2, as each dollar invested leads to an increase of $2 in the regional economy.

In general, the total addition to the economy can be expressed as a function of the marginal propensity to consume MPC:

(Eq. 10) Addition to economy = Investment in Region $(1 + MPC + MPC^2 + MPC^3 + \ldots)$

So long as MPC is less than 1, this sequence converges to 1/(1-MPC). The factor (1-MPC) is the marginal propensity to save, so the multiplier effect increases inversely with the marginal propensity to save:

(Eq. 11) Multiplier Effect = 1/(1-MPC)

For example, if the marginal propensity to consume increases from 0.5 to 0.75, then the marginal propensity to save drops to 0.25. If so, then more money goes into the economy. The total addition to the regional economy would be:

(Eq. 12) $1 million (1+.75+.75(.75)+(.75)(.75)(.75) …) = $1million/(.25) = $4 million

With less money going into savings, the multiplier effect jumps from 2 to 4.

The multiplier effect would apply both to the construction phase and to the operations phase of a project. For infrastructure projects, however, since investment costs are so much higher than continuing costs, the greatest interest is in the multiplier effect from the investment. Multipliers are typically found to be between 2 and 3 for transportation and other infrastructure projects. Note that the multiplier effect relates only to the money spent within the region, so that a project that imported costly materials and used highly automated equipment would have a much lower regional impact than a more labor intensive project that used local labor and materials.

The presence of a multiplier effect motivates governments to initiate stimulus programs during a recession. In the short-run, the stimulus will be most effective in reviving the economy if it is directed toward projects and programs that direct money toward people who will be likely to spend most of what they receive. The long-run economic benefit will depend upon the success of the project in providing permanent jobs, making society more productive, or enabling other economic benefits to society.

Long-Term Economic Impacts: Gross Regional Product

The most common economic measure used to monitor the health of the economy is the **gross domestic product (GDP)**, which equals the sum of private consumption C, investment I, and government expenditures on goods and services G plus exports E minus imports M:

(Eq. 13) $$GDP = C + I + G + E – M$$

The growth in the economy is measured as the change in GDP, and growth in GDP is generally viewed as a critical objective for a nation. A growing economy provides opportunities for more jobs, higher wages, provision of more goods and services, and higher profits for companies. If GDP declines for two successive quarters, then the economy is said to be in a recession. Unemployment rises during recessions, wages may fall, and company profits decline. Thus, maintaining GDP is an important economic objective for a nation.

GDP is not a perfect measure, in part because there is more to life than economics. Even in the realm of economics, however, there is a major problem with GDP, because it fails to account for the losses associated with the depreciation of the capital stock of the country. Machines wear out, buildings age, infrastructure deteriorates, and these losses from depreciation will not be captured until and unless repairs are made or facilities are replaced. The net domestic product is calculated by subtracting total depreciation from GDP. Net domestic product is less commonly used because it is difficult to estimate depreciation of assets, while it is relatively easy to monitor consumer purchases, investments, government expenditures and foreign trade. Since the two measures will usually rise and fall in tandem, the GDP figure is what is most frequently used.

GDP is an aggregate measure that will not reflect conditions for particular regions, groups of people or sectors of the economy. However, similar measures can be estimated for each region of a country. The **gross regional product (GRP)** would be defined in the same manner, with the various factors defined so as to apply to the region, not to the nation. As with the national economy, growth in GRP will be a major economic objective for any region.

Jobs and average income are other important aspects of the regional economy. Adding jobs to the regional economy is always viewed positively, but especially so during a period of high unemployment. Higher-paying jobs are preferred, and local governments may provide tax breaks and other incentives to attract or to retain companies that have such jobs.

Economic models can be constructed to predict the impact of infrastructure investment on the regional economy. Such models may be able to show that transportation investments will make the region more attractive to new businesses or that investments in dams and irrigation will make local agriculture more profitable, leading to growth in all activities related to agriculture. Analysis may also show that investment in infrastructure is expected to have a measurable impact on congestion, public safety, or public health. Savings in time, reductions in risk, and improvements in health can be translated into economic benefits by using the average value of time for commuters, the expected savings in accident costs, and the expected reduction in health care costs. While such benefits do not result in cash flows that help pay for infrastructure investments, they are quantifiable factors that can help justify (and gain public approval for) public investments.

Trade

A great deal of infrastructure investment is based upon projections for population growth and growth in regional economies. Over the long-term, both types of growth depend to a large extent upon forces that act on a national or international scale, such as technological change and trade. **Technological change** results in new products, new materials, new development opportunities, and new processes for manufacturing and distribution. Over time, there can be marked changes in what types of things are produced, how and where they are produced, and how they are distributed around the world. These changes influence and respond to changes in **economic geography**, i.e. the location of people and economic activities throughout a region, a nation, or the world. And it is these changes in economic geography that require and motivate many investments in infrastructure.

Trade is the exchange of goods among regions or countries. Transportation makes trade possible. Differences in regional resources, economies of scale in production, and differences in costs and capabilities make trade desirable. The ability to exchange currencies of different countries and to transfer monies between countries makes trade financially feasible. The ability of wealthy countries to buy vast amounts of goods and materials makes trade flourish.

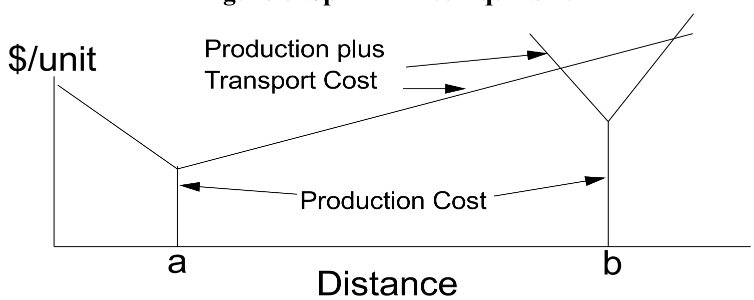
Two key concepts are helpful in understanding how trade works and why trade is important. First, if it is possible to produce something for a lower cost in one region than in another, then there is an opportunity for trade, but only if transport costs are sufficiently low. **Spatial price equilibrium** is the process by which transport costs and manufacturing costs together determine prices for products that can be produced in one area and sold in another. Second, it makes sense economically for different regions to exploit their **comparative advantage**, i.e. to concentrate on what they each do best. Understanding these concepts is essential to understanding the global economy, and recognition that there is a global economy is essential for understanding the kinds of infrastructure investment that will be needed to support industrial production, trade, and population growth.

Spatial Price Equilibrium

To begin, consider a product that can be made in two locations. At location "a", production costs are lower than at location "b". The producers at "a" and "b" compete with each other for business in their region. Although costs are lower at location "a", there are two major reasons why they might not capture all of the business. First of all, costs are not prices. Manufacturer A may decide to charge whatever Manufacturer B charges, so that they will share whatever market is available – and Manufacturer A will have higher profits. Second, transportation costs must be added to the manufacturing costs, and the prices for the products must cover the total cost.

Figure 6 illustrates how transport costs will affect the markets captured by each manufacturer. The x-axis of this chart represents distance. Manufacturer A is located at point "a" and Manufacturer B is located at point "b". The y-axis represents the sum of manufacturing and distribution cost. The costs of manufacturing M_a and M_b are indicated by the vertical lines at a and b; costs are much lower at a.

Figure 6 Spatial Price Equilibrium



Assume that transport costs T_{ax} from Manufacturer A to any potential location X are proportional to the distance D_{ax} from the manufacturer:

(Eq. 14) $T_{ax} = k_{ax}D_{ax}$

Thus, if Manufacturer A decides to market its product at location X, then the total cost will be:

(Eq. 15) $C_a = M_a + T_{ax} = M_a + k_{ax}D_{ax}$

A similar equation would apply for Manufacturer B:

(Eq. 16) $C_b = M_b + k_{bx}D_b$

The total costs C_a and C_b are both plotted in Figure 6. The costs for each manufacturer are Y-shaped, as total costs rise linearly by moving in either direction in this two-dimensional figure. The slope of the total cost line is the cost per mile for transporting the product, which is k_{ax} for Manufacturer A and k_{bx} for Manufacturer B. The slope is steeper for Manufacturer B, indicating that transportation costs are more expensive for that manufacturer. Manufacturer A will presumably capture the market for all locations where its total costs are less than those of Manufacturer B. At points where they are equal, the manufacturers will share the market. In the two-dimensional world depicted above in Figure 6, the total cost lines intersect in two places, one just to the left of Manufacturer b's location on the graph and one a little further to the right of that location. This indicates that Manufacturer B will only be serving its local market, while Manufacturer A will capture all of the rest.

In general, if two manufacturers of identical products are competitive in a market, then they must be charging the same price at that location. For a manufacture to compete and make a profit, the sum of their production cost plus transportation cost must be less than or equal to the prevailing price at that location. Prices will vary from one location to another, reflecting the differences in production and transportation cost. Over time, if transportation and production technologies are stable, a spatial price equilibrium will be achieved, and the markets served by each manufacturer will be well-defined.

Of course, neither production nor transportation technologies remain stable for very long. As we have already seen in this chapter, transportation costs have declined dramatically over the past 200 years, enabling today's manufacturers to compete globally. With low cost global distribution feasible, it makes sense a) to have large manufacturing facilities that take advantage of whatever economies of scale can be found in manufacturing and b) to have those manufacturers located in regions where costs are lowest, whether because of local labor rates or the local energy costs or the geographical position relative to sources of inputs and major markets. Because of the tremendous improvements in freight transportation productivity, it is now feasible to manufacturer many consumer goods in Asia, where labor and production costs are very low, and to ship those goods on large container ships to major ports for distribution throughout the rest of the world.

Comparative Advantage

The unequal distribution of resources, including capital and skilled labor as well as natural resources, is another force promoting trade. Because of accidents of location or history, one region may be able to produce certain products at a lower cost or higher quality than other regions. If this region makes an excess amount of such products, then it can sell them to other regions and use the proceeds to purchase other types of goods from those regions. For example, one country may be very good at making automobiles, while another country is very good at agriculture. Opportunities for trade would seem pretty clear: trade automobiles for food, and allow the country to concentrate on the products where they are the best.

The potential benefits of specialization were first highlighted nearly two hundred years ago by David Ricardo, who developed the theory of **comparative advantage** in 1817. Samuelson summarized this theory as follows:

> "Whether or not one of two regions is absolutely more efficient in the production of every good than is the other, if each specializes in the products in which it has a *comparative advantage* (greatest *relative* efficiency), trade will be mutually profitable to both regions. Real wages of productive workers will rise in both places."[2]

[2] Paul Samuelson, **Economics: An Introductory Analysis**, McGraw-Hill Book Company, New York, 1964, 6th edition, p. 665.

This theory is the basis for reducing tariffs and other barriers to trade. Tariffs are taxes that are charged on inputs as a means of protecting local manufacturing. However, the theory of comparative advantage indicates that it is better to allow imports, so that local workers and local capital can be put to work more productively in areas where the region enjoys its greatest efficiency relative to other regions.

Currency Exchange and International Banking

International trade depends upon a banking system that is able to do two things. First, there must be a common medium of exchange, so that the money used in one country can be used or converted into an amount of another country's money that has the same value. Second, it is necessary to have some system of credit so that a person in one country can borrow the funds needed to buy goods that will be exported from a second country and perhaps transported and sold in a third country.

Today, when it is easy to stick a credit card into an ATM to get local currency when traveling abroad, it is difficult to imagine how important – and how difficult - it was for traders to have access to a banking system in order to carry out their business without personally carrying vast sums wherever they went.

The exchange rates between currencies can be based upon market forces or regulatory forces. Major newspapers provide daily reports on the exchange rates for the major currencies. In early 2009, for example, $1.00 was worth about 0.77 euros or, to put it the other way around, one euro was worth about $1.30.

At times, exchange rates will be quite volatile. In September 2008, when I traveled to Ireland, the euro was worth $1.60. While I was in Europe, there was a worldwide credit crisis, major banks appeared in imminent danger of collapse, and the value of the euro dropped to about $1.35 by the end of my vacation. Although the prices of our hotels and our meals remained unchanged – in euros – it appeared to us as though everything was now 15% off! This change made our trip a little bit cheaper, but this same change affected every transaction between anyone in the U.S. doing business with anyone in Europe. Suddenly, everything priced in euros was 15% cheaper for anyone who had dollars to spend – and everything priced in dollars was 15% more expensive for anyone who had euros to spend. A change of this magnitude is equivalent to putting a 15% tariff on everything exported from the US into Europe and having a 15% sale on everything imported to the US from Europe. Changes of this magnitude have broad repercussions on international trade and travel, even without a credit crisis.

A credit crisis can be devastating to trade and economic growth. Without credit, it is hard for businesses to get the loans they need to expand production and it is hard for consumers to borrow money to buy houses, cars and other items. The credit crisis in late 2008 and early 2009 resulted in stock markets plunging, the auto industry teetering upon bankruptcy, and many banks and investment banks collapsing. Without credit, trade declined abruptly and the world economy slipped into a serious recession.

Making Decisions: Utility and Sunk Costs

Economists use the concept of **utility** as a way to understand how individuals make decisions. It is assumed that people act so as to maximize their utility, subject to budgets for both time and money. Utility is a useful concept, even though few of us will be able to say why we do or do not do something or why we prefer one product over another. It is possible to study utility by documenting the choices that people make or by conducting surveys, i.e. by considering what are called **observed preferences** or **stated preferences**. Analysis of actual choices is likely to provide better insight into behavior, but it is much easier to obtain detailed information by using surveys and documenting stated preferences. For example, a survey could ask people to say whether or not they would buy a particular product for various prices. More complex surveys could be devised to explore quality of service, timing, and other factors that might be important in addition to price.

For example, consider the journey to work. A person may have the choice of driving alone, riding with a friend, or taking the bus. Direct observation may show that this person drives alone 60% of the time, rides with a friend 20%

of the time, and takes the bus 20% of the time. An interviewer can probe further, seeking to understand how cost, travel time, work schedules, weather, errands, and shopping factor into the decision. Utility models may be constructed based upon the actual decisions or the stated preferences. These models will typically include variables that reflect cost, service quality and convenience. The result of a utility analysis will be something like "people seem to value the time spent commuting at something close to their average wage". Such an estimate of the value of time could be used in estimating the benefits of a transportation project that saved time for commuters or other travelers.

Economic decisions concern future costs and benefits. Money spent in the past should not affect what we decide to do today, and such costs can be viewed as **sunk costs**. For instance, if you are about to buy a new car, and you plan to trade in your old car, it does not matter – to you or to the car dealer – what you paid for that car. What matters is what the car is worth today, which will depend upon the condition of the car and the demand for used cars. On a larger scale, when trying to decide whether or not to buy or sell a building, it does not matter what that building cost to build. It is only the market value of the building that will affect the price. Of course, if you have yourself put a great deal of money into buying a car or your house, you may well perceive that the car or house is worth a lot more than anyone else does, but that is only a factor in deciding whether you are willing to part with it. The current market value is what should enter your economic analysis.

Summary

This chapter has introduced supply, demand, equilibrium, competitive and monopolistic pricing, productivity, utility and other economic concepts that are relevant to project evaluation. These concepts provide a framework for thinking about needs, projects, and project evaluation.

Supply and Demand

The **supply function** describes the amount of output that will be provided as a function of the price per unit that is sold. The **demand function** describes the amount of output that will be purchased as a function of the price per unit. The **equilibrium price** is the price for which supply will equal demand. In most complex systems, there will be continual changes in both supply and demand, and it is more realistic to think about systems moving toward equilibrium rather than always being in equilibrium, especially for systems where it is costly and time-consuming to adjust capacity. Congestion, delays and poor quality are likely when demand exceeds supply, while underutilization of equipment and reductions in the work force of suppliers will be common when supply exceeds demand.

The **elasticity of demand** with respect to price can be estimated by observing the effects of price changes on demand. If demand is elastic, then demand will be more responsive to price changes, and an increase in price will lead to a decrease in total revenue. Demand tends to be more elastic in the long-run than in the short-run, as people and businesses will generally find ways to reduce their dependence on higher-priced goods and service.

Productivity

Productivity is defined as the ratio of output to input. Improving productivity is an important objective, because productivity improvements make it possible to produce more goods and services using fewer people and resources. Many projects eliminate productivity problems related to bottlenecks, constraints on usage, inadequate control, or outmoded facilities. Productivity may also be improved by changing the structure, design and size of networks or facilities so as to achieve economies of scale, scope, or density. **Scale economies** exist when expanding the size of the system leads to reductions in average cost. **Scope economies** exist when it is cheaper to use facilities for multiple uses. **Density economies** occur in a network when more volume is concentrated on each route.

Pricing

In a **competitive environment**, no individual supplier has the power to set prices, and prices will fall to marginal cost. In infrastructure-based systems, **marginal cost pricing** will generally be well below average cost as long as the system is operating below its design capacity. Thus there may be a need for price regulation or subsidies to ensure that revenues are sufficient to cover total costs of operation. If demand approaches capacity, then marginal costs for both users and operators will rise as delays and high utilization levels make it difficult to use and maintain the system.

If a supplier has a **monopoly**, it can set prices well above marginal costs so as to maximize profits. Monopolies may also be slow in adopting new technology or expanding capacity to meet demand, and they may display little concern for service quality. However, for many infrastructure-based systems, there are tremendous economies of scale and density, so that the cost of service can be greatly reduced by limiting competition. Thus, many transportation companies and public utilities are allowed to operate as monopolies in order to achieve cost savings, while being subjected to regulation in order to ensure reasonable prices and service.

Measuring and Improving the Economy

Public officials and the general public are naturally interested in expanding economic output, which is commonly measured as the **gross domestic product (GDP)**. GDP is the sum of all private consumption, private investment, government expenditures and net exports. Other measures of the economy include **total jobs**, **unemployment** levels, and **average income** per person or per family. All of these measures can be developed for a region as well as for a country.

A major project will have both a direct and an indirect effect on the regional economy. The direct effect will be related to the jobs created and the expenditures required to complete and subsequently to operate and maintain the project. In addition, there will be a **multiplier effect**, because the people who work on the project and the companies that sell materials to the project will spend much of what they earn, whether on food or cars or housing, and other people and other companies will enjoy some added income.

Trade

Trade allows regions to specialize in economic activities where they have a **comparative advantage** relative to other regions. By producing more of what they need for some types of products, they are able to trade for other things that they need or desire. The ability to trade is dependent upon the ability to transport goods efficiently between regions, because of **spatial price equilibrium**. In order for trade to make sense, the cost of producing something in one location plus the cost of transporting the product to another location must be less than the price that can be charged in that location. Investments in transportation systems have produced dramatic reductions in transport costs, thereby enabling the shift of manufacturing, mining, agricultural production, and other activities to the regions of the world with the lowest costs. The global economy reflects low transportation costs and the fact that there are generally high economies of scale in production.

Banking and currency exchange are another essential aspect of global trade. Exchange rates between currencies of different countries may be determined by market forces or by regulations. Over time, **exchange rates** may vary substantially, which will tend to change the patterns of trade by making some countries relatively cheaper and other relatively more expensive. Growth in trade and changes in trade routes are important considerations in many infrastructure projects.

Making Decisions

Despite the fact that we know ourselves often to be less than rational in our decisions, economists assume that individuals will generally make decisions so as to maximize their own **utility**. Utility is a rather vague – but thoroughly useful – concept that can incorporate disparate factors such as cost, convenience, reliability, safety or aesthetics that might affect our choice of a new car, a new house, or where to eat dinner. By observing what decisions people make (**revealed preferences**) or asking people about hypothetical choices (**stated preferences**), it is possible to infer what factors they consider in making choices. Those who plan projects must, at some level, consider how many people will use the completed project (road, water system, park or office building) and how much they will be willing to pay for their use of it.

When evaluating proposals, only future costs and benefits need to be considered. Money spent in the past is a **sunk cost.** Whether that money was well-spent or wasted does not and should not affect decisions concerning what to do in the future.

Manchester, New Hampshire

Water power enabled Manchester to become a dominant manufacturing center during the 19th century. When the mills closed, the old buildings were transferred into office space museums, restaurants, and small businesses, and walkways were constructed along the Merrimac River in order to attract visitors.

Public Perspectives: Economic, Environmental and Social Concerns

Happiness lies not in the mere possession of money; it lies in the joy of achievement, in the thrill of creative effort. The joy and stimulation of work no longer must be forgotten in the mad chase of evanescent profits. These dark days will be worth all they cost us if they teach us that our true destiny is not to be ministered unto but to minister to ourselves and to our fellowmen. ... Our greatest primary task is to put people to work. This is no unsolvable problem if we face it wisely and courageously. It can be accomplished in part by direct recruiting by the government itself, treating the task as we would treat the emergence of a war, but, at the same time, through this employment, accomplishing greatly needed projects to stimulate and reorganize the use of our natural resources.

Franklin D. Roosevelt, president of the United States, First Inaugural Address, March 4, 1933
(*Record,* 73 Congress, Special Session of the Senate, pp. 5-6)

Overview

The public sector, which is responsible for many kinds of infrastructure systems, takes an entirely different perspective than the private sector when identifying needs and evaluating potential projects. The primary motivation for the private sector projects will be the financial returns to the owners, not the broader effects on the economy or society. For the public sector, the motivation is not to earn money, but to satisfy public needs or to promote growth in the economy. Financial issues are important, but not necessarily dominant, and every major project will have multiple purposes and multiple measures of effectiveness (Table 1). Social and environmental impacts are central to the public evaluation process, and equity in the distribution of costs and benefits will be critical. In dealing with non-monetary objectives, cost effectiveness will be a more relevant concept than return on investment: which of the proposed alternatives is the best way to achieve the desired objectives?

Table 1 Examples of Public Infrastructure: Multiple Purposes and Multiple Measures

Type of Infrastructure	Purpose	Measures
Transportation	Mobility Accessibility Regional competitiveness	Service levels (travel time, congestion) Cost of transportation Fuel consumption Safety Emissions
Dams	Flood control Irrigation Hydropower Recreation (boating, swimming, camping, picnic sites)	Risks associated with floods Volume of water available for irrigation Land area to be irrigated Electricity production (cost & revenue) Impact on wildlife
Water & sewage	Clean water for consumption Water for industry & irrigation	Volume of water available for each type of use Cleanliness (risk of disease) Cost per unit
Public Housing	Housing for elderly Housing for low income residents Housing for homeless	Number of units Size and quality of buildings Cost per unit (construction & operation) Safety & Security Aesthetics
Parks & recreation	Open space for residents Protect environment Aesthetics	Open space as % of total space Visitors per year Diversity of wildlife Safety

Another difference is that the time frame of the analysis will be much longer for the public than for the private sector, as the public entity is presumed to endure indefinitely. The long time frame requires the consideration of sustainability – will projects or programs be sustainable over long periods of time taking into account economic, financial, social, and environmental factors?

For many kinds of public infrastructure projects, the tolls, fees, and other direct revenues from the project will be insufficient to cover the costs of the investment. However, the non-monetary benefits could be considerable. A public transportation project may relieve congestion, improve air quality, and promote mobility for those without access to an automobile. While these benefits can at times be quantified by using concepts like consumer surplus or the multiplier effect of new investment, such benefits do not produce cash flows that cover the interest on bonds or the operating costs of the transit agency. If the benefits are clear, and if the public generally believes that these benefits are worthwhile, then public agencies may be able to use tax revenues to supplement the direct cash flows from the project. If taxes are used to finance a project, then that project will be competing not just against similar projects, but against all of the other projects that might be undertaken by that city, state or country. Transportation projects compete with housing for the elderly, and water projects compete with health care projects. Decisions for or against projects will be political decisions, and the relative importance of various kinds of costs and benefits will be subject to considerable debate.

To complicate the situation further, a project will also be evaluated in terms of its impact on the community:

- Economic impacts, including employment, regional economic growth, regional competitiveness
- Environmental impacts, including air quality, water quality, noise, loss of wetlands, and impact on ecosystems.
- Equity, including the distribution of costs and benefits across regions and groups of the population and the relative impact on current and future generations.
- Aesthetics, including the appearance of the new infrastructure, its effect on neighboring areas, and its effect on long-term changes in land use.
- Other social impacts, including such things as impacts on communities during construction, displacement of residents, and long-term changes in population distribution

Multiple objectives and multiple measures mean that these projects are inherently complex, with many conflicts possible among different objectives. The decision-makers ultimately will include the public, who may have a chance to vote for or against the funding sources proposed for a project, and the politicians or appointed officials who must justify their decisions to the public in order to be re-elected or to retain their jobs. Large projects will be politically sensitive, and it will be necessary to consider and to balance all of the conflicts. There will be real and apparent conflicts of interest among those who are supposed to be proposing, evaluating, and approving projects. It will not be possible to satisfy everybody, and there will likely be determined opposition to almost any major project. People commonly do not want anything built too close to them, even if they are going to be major beneficiaries of the project. This phenomenon, which can lead to intense community opposition, is known as the NIMBY response: "not in my backyard".

In summary, a major public project will be evaluated by many different groups of people, from many perspectives, with varying concerns for the relative importance of various features of the projects, and with potential disputes about how to measure or estimate costs and benefits.

Benefit/Cost Analysis

Public projects require an evaluation process that includes, but is much broader than financial analysis. A simple dictum is mandated both by law and by common sense: for any public project, the total benefits should exceed the total costs. This does not mean that every project with more benefits than costs is a good project; it simply means that projects whose costs exceed their benefits are bad projects that should not be funded by the public. This may seem to be a rather obvious principle, but it surely is necessary, as there are many instances of projects being built, at taxpayer expense, whose costs far exceeded their benefits. There are even names for such projects: "gold plated" projects that could have been constructed for far less money; "pork barrel" projects that were approved in order to get a crucial politician's support for some larger political scheme; and "white elephants" that are constructed at great expense, but that afford no greater benefits than ordinary elephants! The political process can provide a means to fund many different projects, and it is possible that many projects will be "earmarked" (i.e. specifically authorized in the legislation) rather than subjected to a rigorous examination of their costs and benefits. A requirement that the benefits of every project should exceed the costs is therefore a step toward a more rational allocation of public funds and a defense against mismanagement, stupidity, and corruption.

Measurement will be a major problem in determining whether or not costs exceed benefits: how can different types of non-cash costs and benefits be converted to monetary terms? How can important benefits such as savings in travel time or reductions in risk of accidents be converted into monetary terms? What about aesthetics? In some cases, the monetarization is straightforward; in other cases it is convoluted and controversial; and in still others it is essentially impossible.

For example, consider a proposal to construct a new highway that is intended to provide a safer, more attractive route around the congested core of a city. The basic question is whether the savings in travel time, the expected reduction in fatalities, and the prettier route justify the cost and the environmental impacts of constructing the highway through the surrounding region.

<u>Travel time</u>: Traffic engineers are able to model how commuters, truckers, and others will use the new facility, and they will be able to predict traffic flows on the new facility along with the changes in traffic flows on other facilities. Based upon the changes in traffic flows, they will be able to predict travel times on the new road and changes in average travel time on each segment of the existing network. The overall effect can be summarized as a reduction in travel time measured as vehicle-hours per day or per year, with details for commuters, local delivery trucks, long-distance trucks traveling through the region, and any other group of interest. The value of these time savings is commonly estimated by making a series of assumptions. For instance, the time saved by commuters could be valued by using the average hourly wage for workers in the region, and the value of time saved by truckers could be valued by using the average hourly wage for truck drivers, the hourly cost of truck ownership, and the hourly value of the contents of the truck. Some might argue that something less than the average hourly wage should be used, and others might challenge the methodology used to estimate the hourly cost of truck ownership, but these estimates of the value of time are commonly accepted, and the benefits are clear and verifiable.

<u>Safety</u>: estimating the value of the safety benefits will be trickier. Traffic engineers will be able to predict the number and severity of accidents based upon traffic flows and highway geometry, and safety analysts can use past history to quantify the expected damage to vehicles and the highway. However, no one can readily place an economic value on the most important safety benefits, namely a reduction in the expected number of injuries or fatalities. Instead, departments of transportation in some countries will consider the value to society of reducing fatalities and serious injuries resulting from automobile and other transportation accidents. In the United States, the U.S. Department of Transportation uses a value of approximately $2.5 million in its risk analysis. This amount represents the benefit to society of eliminating a single, future fatality. It does not represent the value of a human life, for it is impossible to say who would have been hurt or killed. In effect, the $2.5 million can be viewed as an aggregate benefit to all users of the system of a slight reduction in the probability of a fatal accident. Every user benefits because the probability of an accident is reduced.

<u>Aesthetics</u>: now we are close to the "impossible" in trying to quantify the benefits of the new highway. Whether or not aesthetics is viewed as an important component of the decision will depend upon the political situation in the region. It could be viewed as an afterthought, which might mean planting some flowers along the right-of-way, or it could be a major design consideration, as in the construction of roads in national parks or the construction of parkways into major cities. The argument may well boil down to someone showing artist's renditions of the options (or photos of similar projects elsewhere) and saying something like "isn't it worth spending an extra $5 million to get a nice

facility?" If people agree that "$5 million" is a small amount, then they will choose the more aesthetic option. If people note that $5 million" is equivalent to the park budget for 20 years, then they will probably be vocal in their opposition!

Economic Impacts: Measures Related to the Regional or National Economy

Governments and public agencies will be concerned with the effects of projects on the local, regional, or national economy. Primary measures will include gross regional or national product, jobs created or lost, average income, and personal and industrial productivity. These economic benefits could come from several types of benefits:

- Construction jobs and income
- The multiplier effect of construction
- Jobs and income related to the eventual operation of the new project
- The multiplier effect of operation of the new project
- Continuing productivity benefits resulting to citizens, users, industries or public agencies as a result of the project
- Growth in the economy related to the productivity benefits provided by the project

For example, consider the construction of a toll road. The initial construction may take two years, provide hundreds of jobs, and increase sales of construction materials within the region. The direct expenditure of several hundred million dollars would have a multiplier effect that would more than double the economic benefit to the region during the period of construction. Once the toll road is opened, there could be long-term jobs for toll-collectors (or for those who maintain any electronic toll collection devices) and for highway maintenance forces, providing both a direct and a multiplier effect to the regional economy. The toll road presumably offers benefits to the public in terms of higher capacity for rush hour traffic, reduced risks of accidents, and perhaps reduced travel time. With less congested highways, the region may be able to continue to attract new businesses and to absorb additional population growth. Land near interchanges is likely to increase in value and attract hotels, restaurants, trucking terminals, warehouses, and other businesses that depend on highway access or serve highway users.

These benefits could be offset by the impacts of both the construction and the continued operation of the highway. Disruption of normal activities can be a major economic cost of a highway project. Although construction of a new highway interchange will ultimately relieve congestion, it may cause increased delays for a year or two. Once the highway is built, it may act as a barrier that limits access between different parts of the region. Over time, land use will adjust to the existence of the highway, which could result in rapid growth in some areas and equally rapid declines in other areas.

Environmental impacts

Any project will alter the complex relationships between what might be thought of as the natural world and the manmade world. Construction activities convert more space from the natural to the manmade world. Projects require construction materials such as wood, steel, and concrete which ultimately depend upon activities such as forestry, mining, and manufacturing that certainly disrupt and may at times destroy the environment. Continued operation and maintenance of infrastructure require energy and other materials that ultimately come from the natural world. Normal operations, accidents and decay may release toxic substances that can affect air quality, water quality, soil composition and limit or destroy the ability of plants and animals to survive near project sites. Constructed facilities will cast shadows, they may be noisy, and they might just be ugly or interfere with people's day-to-day lives. Whether or not the benefits of the project are worth the environmental costs will always be a relevant question, especially when those receiving the benefits are not those who bear the costs. The extent to which this question is considered will depend upon the social, cultural and political institutions.

In many countries, developers must prepare an environmental impact statement (EIS) that at least states the goals of a project, presents major alternatives for achieving these goals, identifies the major environmental impacts, and suggests ways to mitigate the most negative impacts. Preparing an EIS ensures that information is made available to the public and to public officials who must approve a project; the extent to which environmental considerations affect decisions about a project may well depend upon legal and political battles.

Courts and legislative bodies are well-structured for dealing with controversial trade-offs between environmental and economic issues and the extent to which developers must deal with environmental concerns. Legislation has limited the development of wetlands, promoted soil and water conservation, required more fuel-efficient automobiles, and limited land use via zoning and other restrictive matters. However, courts and legislative bodies are not well-structured for dealing with the underlying science, as evidenced by the controversies related to the extent of, the causes of, and the possibilities of responding to global warming and climate change.

Mankind has certainly transformed the world. Over a period of many thousands of years, humans have converted vast portions of the earth's land area to agriculture, drained innumerable wetlands, developed much of the land near the oceans, seas, and major rivers, and cut down vast areas of forest. These activities have changed the chemistry of the atmosphere, altered the natural flows of fresh water, and restricted the natural habitats crucial for many species of plants and animals. These activities have also allowed humans to prosper by helping to ensure adequate food supply, clean water, housing, abundant energy sources, and protection against floods and other natural disasters. In the future, we will still eat, drink, use energy and improve the way we live – but we will have to pay more attention to our impact on the environment.

There will be a whole of range of environmental issues that must be addressed in evaluating any major project, and there will be many major projects whose primary objective will be to improve the environment. Environmental issues will range from very local debates as to what gets built in whose backyard to regional and national questions related to the use of resources to international questions concerning the future of the planet. Since we can't expect to answer all of these questions every time we want to build a new hotel or new segment of a highway, we need to provide a reasonable structure for addressing these issues within the project evaluation process.

<u>Environmental Concerns</u>

Let's start by considering some basic environmental concerns. Soil, water, sunlight, and temperature are among the factors that determine what plants can grow in any location. Plants that are well-adapted to local conditions will prosper, those that are poorly adapted will struggle, and those that cannot survive the extremes of temperature or hydrological conditions will never gain more than a short-term foothold. Insects, birds and small mammals are necessary to the propagation of many plant species, and worms, amphibians, and insects make soil into a complex, living community. Animals may feed on plants or other animals, and they prosper in locations where there is an abundance of food along with sufficient cover for their own safety and appropriate places to raise a family, whether in trees, burrows, rotten logs, stream banks, or wetlands.

Left undisturbed, any location will eventually develop with a characteristic set of plants and animals that can survive or flourish within the constraints posed by soil conditions, sunlight, and climate. Biologists have identified distinct **ecosystems** that can be characterized by the kinds of plants and animals that will be found there. Within any healthy ecosystem, there will be a diversity of species, each of which is somehow related to the health of the overall system. Pileated woodpeckers make holes in dead trees as they look for insects, and these holes are later used as nesting sites for chickadees. When the dead tree finally collapses, it will provide cover for mice and other small rodents, as well as an ideal place for fungi to grow or for grouse and hares to hide.

In many cases, there are species that will only be found in certain ecosystems, so that they can be considered to be **indicator species** that are useful in documenting the existence of unusual ecosystems. For instance, wood frogs lay their eggs in vernal pools, which are small pools that are formed in rainy seasons or in spring as the snow melts. Vernal pools dry up for part of the year, so they cannot support fish, which means that eggs deposited in a vernal pool will be safe from predation from fish. Wood frogs are an indicator species for vernal pools. A single female wood frog lays hundreds of eggs in the early spring, so if the pool retains water long enough for the eggs to turn into tadpoles and for tadpoles to grow into tiny frogs, then the wood frogs will prosper. If the vernal pools are filled as part of the process of building a parking lot or a suburban sub-division, then the wood frogs will die off.

In most regions, a few types of ecosystem will dominate the landscape, while a dozen or more other types will be commonly scattered throughout, and some will be found only in a few locations. Preserving the rare ecosystems may be essential for preserving bio-diversity, as there will be plants and animals that are only to be found in those locations. Preserving a good distribution of the more common ecosystems will prevent populations of plants and animals from becoming too isolated. Preserving large tracts of the dominant ecosystems will ensure healthy conditions for all of the region's most common species.

Ecosystems can be harmed in several ways. **Pollution** – the introduction of foreign elements into the air, the water, or the soil – may lead to the death of certain plants or insects and of the animals that depend upon eating them. Pollution could be in the form of toxic chemicals that are poisonous to certain species, but it could also just be the introduction of sediment into a pristine stream, thereby making the water quality unsuitable for certain types of fish. Pollution can also refer to the heated water that is discharged from a nuclear power plant, as the heated water will be lethal to the some species, while attracting others that may be alien to the previously existing ecosystem.

Disruptions to the flow and retention of water can have devastating effects on ecosystems. Draining wetlands to increase the land available for highways, housing or agriculture will lower the water table and make the remaining wetlands more susceptible to drought and fire. Extensive development in Florida, for example, has changed the flow of water through the Everglades, threatening the future of what was once the seemingly endless wetlands of southern Florida. More rapid runoff of water means that both floods and droughts are more likely, which means that certain species of plants and animals will have greater difficulty surviving.

Fragmentation of an ecosystem will eventually create areas that are too small to support the wildlife that formerly flourished there. A black bear requires a range of 10 to 100 square miles; if a region that formerly supported large populations of black bears is crisscrossed by roads and disrupted by housing developments and malls, then the habitat will no longer be large enough for the bears to survive.

For species requiring less extensive ranges, it is not so much the fragmentation of the habitat as the total **loss of habitat** that will be decisive. As agricultural land is turned into housing developments or malls, the birds that used to feed on the insects and seeds will have to go somewhere else, and the deer that used to feed on the leftover corn cobs will be hit by cars as they try to feed on the shrubs and gardens of the new developments. Colonies of butterflies and dragonflies will be lost, along with vast numbers of mice, voles, and moles and the hawks, owls, and weasels that feed on them. For migratory birds, the loss of habitat is especially problematical, as they need places to feed and to breed, perhaps on two continents, and they need extensive areas for resting and feeding along their migration routes.

A final threat to ecosystems comes from the introduction of **alien species**. In a well-functioning ecosystem, everything is in balance. Insects or other animals eat some but not all of the seeds, none of the animals eat all of any of the species of plants, and none of the plants grows so rapidly that it crowds out all of the other plants: it is a complex system of natural checks and balances. An alien species is one that originated in a distant ecosystem where it had adapted to competition with the other plants and animals that comprised that ecosystem. It undoubtedly served to control some of the other species, and other species controlled it. However, when introduced as an alien into a new ecosystem, there may be no controls and balances, and an alien species may prosper to the extent that it out-competes and eventually crowds out the native species. Purple loosestrife is a tall, tough wildflower that has a large woody ball of roots; it has numerous flowers on a spike, and it grows profusely in wetlands. When introduced to wetlands in the United States, it faces only modest competition from less aggressive plants, and it has no natural insect competitors. As a result, it can, within a few years, fill the wetlands, creating what is a beautiful purple covering but what is also a barren wetland. As there are no native insects that eat the stalks or the flowers, there are no native birds that are attracted to the plant, and there are no hawks circling to catch any of those birds off-guard. The weeds grow so close together that it is difficult or impossible for muskrats or beavers to keep their channels open, and there is too little space between plants to support families of ducks.

Alien species often get their start when ground is disturbed for some sort of construction project. If these species are not dealt with – which often requires people who search for the first aliens and then pull them out by hand – then they can rapidly spread and destroy many acres of land. The key point to remember is these alien species overflow their niche, eliminating the chance for native species to prosper, and also eliminating the niche that was occupied by insects and animals that depended upon the native plants and animals. Alien species may be beautiful, but they tend to limit biodiversity.

Maintaining the health of ecosystems requires local, regional, and national strategies. One useful concept is **Green Infrastructure**, which refers to the network of natural areas that is necessary to support the diverse populations of native plants and animals that live within a region. This term does not refer to man-made infrastructure that is constructed in an environmentally friendly manner. Rather, it refers to the connected natural system of open spaces, forests, waterways, and wetlands that allows plant and animal species to prosper. Green infrastructure includes the following kinds of components:

- Very large areas of undeveloped land that are able to support and protect habitat for the widest-ranging animals and ensure the continued existence of diverse ecosystems
- Small areas of undeveloped land that protect uncommon or rare ecosystems
- Numerous small or medium-sized natural areas that are large enough and close enough together to avoid isolation of plant and animal species
- Connecting corridors of open spaces that can be used by animals to move between the larger open areas

By acknowledging the existence of and the need for green infrastructure, it is possible for government agencies and conservation groups to develop plans that preserve and protect suitable green infrastructure. National parks, state parks, public conservation lands (e.g. national forests or wildlife management areas) can provide the critical large areas. Smaller parks, wetlands, and private land-holdings can protect enough smaller areas to ensure diversity and density of ecosystems. The hardest part is ensuring that wide enough corridors are maintained between and among all of the open spaces so that wildlife can in fact move throughout the region. The corridors need to be wide enough to be perceived as safe routes for animals to travel. For the largest mammals, 100 to 200 foot-side corridors will be needed. For smaller mammals and amphibians, narrower corridors will suffice. Land adjacent to waterways and wetlands is ideal for use as connecting corridors, as is land next to railroads, power lines, or other infrastructure networks.

Pollution can be controlled by limiting emissions, by confining emissions, or by cleaning up emissions. The cheapest control strategy is to prevent emissions, but that may or may not be feasible depending upon the nature of the process that causes the pollution. Some pollutants are extremely toxic, and even a small release can be hazardous to anyone living close to where the release occurs. Hence, special consideration is necessary in dealing with the most toxic chemicals and spent nuclear fuels or other radioactive substances. Finding a safe means of sequestering nuclear waste is one of the main challenges facing the nuclear power industry.

Climate change caused by excessive emissions of carbon dioxide, methane, and other so-called greenhouse gases is a major challenge for the world in the 21st century. Scientists believe that increasing concentrations of these gases in the atmosphere will trap heat, thereby leading to warmer temperatures. With warmer temperatures, there will be more energy available to power hurricanes, tornadoes, tsunamis and other extreme weather conditions. Warmer temperatures will also accelerate the melting of glaciers and the ice caps, which will raise the level of the oceans and threaten flooding of the many cities and developed regions along the coasts. Changes in climate could also include regional changes in precipitation, which could have major implications for agriculture and for the natural environment.

Environmental Impacts of Projects

Proposals for major infrastructure projects can raise many different kinds of environmental issues. Abutters, politicians, environmental organizations and others are likely to express concerns about some or all of the following:

a. Use of materials in construction and operation
b. Pollution: impacts on air quality, water quality, and soil toxicity
c. Loss of habitat and disruption of ecosystems: Impacts on plants and wildlife
d. Impacts on the local environment (noise, shade, aesthetics)
e. Sustainability or the lack thereof

It will not be possible or necessary to consider all possible levels of impacts for every project that is considered. Regulations can be developed that govern the use of materials and that establish acceptable limits for pollution. Regional plans can help identify the necessary green infrastructure, and zoning can be used to direct development away from the most critical natural areas. Local impacts on noise, aesthetics, and land use will of course be a concern for nearly any project, and some sort of community involvement can be helpful in anticipating and responding to potential problems.

In the United States, a process has been created to ensure that environmental impacts are considered along with the economic and social impacts of any major project or program involving federal funding or approvals. This process emphasizes the need for determining and disclosing environmental impacts in what is called an **environmental impact statement (EIS)**, and it requires developers to consider how to mitigate negative impacts, but it does not indicate what can or cannot be done. That determination is left to the legislatures and the courts. An EIS is required for any major federal legislation or action "significantly affecting the quality of the human environment."[1] The federal agency proposing the changes must prepare the EIS, which must include "a detailed statement of these environmental effects."

> *"The National Environmental Policy Act of 1969 (NEPA), as amended, (42 U.S.C. 4321 et seq., Public Law 91-190, 83 Stat. 852), requires that all Federal agencies proposing legislation and other major actions significantly affecting the quality of the human environment consult with other agencies having jurisdiction by law or special expertise over such environmental considerations, and thereafter prepare a detailed statement of these environmental effects. The Council on Environmental Quality (CEQ) has published regulations and associated guidance to implement NEPA (40 CFR Parts 1500-1508)."*[2]

The Environmental Protection Agency (EPA) is responsible for reviewing the draft EIS and rating it according to two criteria. First, the EPA must decide whether or not the EIS is acceptable in terms of the depth of its analysis and the completeness of its findings. Second, EPA rates the environmental impact according to one of four categories:

- Lack of objections (LO): "The review has not identified any potential environmental impacts requiring substantive changes to the preferred alternative. The review may have disclosed opportunities for application of mitigation measures that could be accomplished with no more than minor changes to the proposed action."
- Environmental Concerns (EC): "The review has identified environmental impacts that should be avoided in order to fully protect the environment. Corrective measures may require changes to the preferred alternative or application of mitigation measures that can reduce the environmental impact."
- Environmental Objections (EO): "The review has identified significant environmental impacts that should be avoided in order to adequately protect the environment. Corrective measures may require substantial changes to the preferred alternative or consideration of some other project alternative (including the no action alternative or a new alternative)."
- Environmentally Unsatisfactory (EU). "The review has identified adverse environmental impacts that are of sufficient magnitude that EPA believes the proposed action must not proceed as proposed."

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[1] The material in this sub-section is based upon EPA's "Policy and Procedures for the Review of Federal Actions Impacting the Environment" October 3, 1984, pp. 4, 19-20. The document is available from EPA's web site (www.epa.gov)
[2] Ibid. p. 4

The EPA review is a major hurdle for any project involving the federal government or requiring federal approval. After a draft EIS is published, time is allowed for public comments concerning what the draft includes or fails to include. The draft EIS and all of the comments and procedural rulings are available to the public on-line. If the EPA finds environmental concerns, it may require substantial changes in the proposed actions or prevent the project from proceeding as proposed. Moreover, if EPA finds the EIS to be inadequate, EPA may require it to be revised or redone, an action that could delay a project for a year or more.

The conditions that would allow the EPA to raise environmental objections are specified by government regulations. Objections can be raised in five situations:

1. *"Where an action might violate or be inconsistent with achievement or maintenance of a national environmental standard;*
2. *"Where the Federal agency violates its own substantive environmental requirements that relate to EPA's areas of jurisdiction or expertise;*
3. *"Where there is a violation of an EPA policy declaration;*
4. *"Where there are no applicable standards or where applicable standards will not be violated but there is potential for significant environmental degradation that could be corrected by project modification or other feasible alternatives; or*
5. *"Where proceeding with the proposed action would set a precedent for future actions that collectively could result in significant environmental impacts."*

In other words, EPA must have a clear reason for raising objections, and other guidelines and policies will be used to determine whether proposed actions are acceptable or not. More stringent guidelines are in place for finding a proposal with environmental objections to be environmentally unsatisfactory:

1. "*The potential violation of or inconsistency with a national environmental standard is substantive and/or will occur on a long-term basis;*
2. *"There are no applicable standards but the severity, duration, or geographical scope of the impacts associated with the proposed action warrant special attention; or*
3. *"The potential environmental impacts resulting from the proposed action are of national importance because of the threat to national environmental resources or to environmental policies."*

Thus, the environmental review process places the onus on the proposing agency to identify the potential impacts, while establishing an agency with the necessary skills and responsibility to review and interpret the EIS. The criteria cited above could be quite qualitative, leaving approval up to the judgment of the EPA. Since the whole process is open to the public, it is possible for groups opposed to any action to make their objections to EPA.

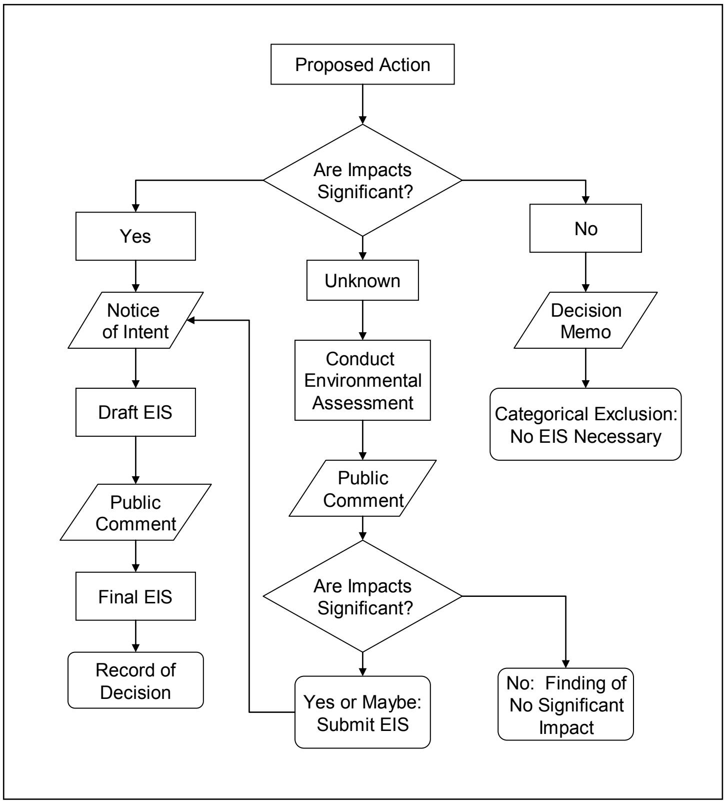
Figure 1 summarizes the review process used by EPA. If a major project or action is proposed, the first step is to determine whether or not there will be significant impact on the environment. If EPA believes that there will be no such impact, then it can allow the project to proceed without an EIS. If EPA finds that there will be significant impact on the environment, then the proponents of the project must prepare a draft EIS, which will be available for public comment and review by EPA prior to submission of the final EIS. EPA will then make its decision, as described above. If EPA finds that the environmental impact is unknown, then an initial environmental assessment can be required, which could lead to a finding of no significant impact or to the preparation, review, and revision of an EIS.

A great deal of judgment is involved in preparing and reviewing environmental impact statements. EPA has developed two sets of checklists of questions that might be asked in order to guide reviewers as they evaluate an EIS.[3] The first set of checklists address general areas of environmental concern that might apply to any proposed project: energy management, habitat preservation, landscaping, water use, and pest management. In each area, EPA has summarized

[3] Science Applications International Corporation, "Pollution Prevention – Environmental Impact Reduction Checklists for NEPA/309 Reviewers", Final Report, EPA Contract No. 68-W2-0026, January 1995

the relevant scientific factors and posed a series of questions that could and probably should be asked when reviewing any project. The second checklist provides questions that address the problems likely to be encountered in different types of projects. In each special area, such as a transportation or waterway project, the guidebook includes a brief summary of the likely problems and then provides several dozen questions that could be asked to determine how well an EIS has addressed issues that might be anticipated.

Figure 1 Summary of NEPA Decision Process



Social Impacts

Almost any project will have social impacts that may be related to the users of the project, people who live near the project, people who are displaced or competitively disadvantaged because of the project, or people who are hurt or whose lives are hindered as a result of the construction or operation of the project. Social impacts could be positive as well as negative, but it is the negative impacts that must be considered most carefully. Positive social impacts will help make a project more attractive, whereas negative impacts may be sufficient to arouse intense public opposition that prevents or markedly restricts a project. Anticipating negative impacts is therefore something that should be done early in the evaluation process, so that there will be an opportunity to adjust plans so as to reduce the negative impacts or to provide means for mitigating them.

Major projects may have far-reaching consequences that are difficult or impossible to quantify or comprehend. In some cases, projects that appear at first to be wholly desirable turn out to have unexpected consequences that are viewed very unfavorably by some people. In their famous study of Middletown, Robert and Helen Lynd reported that some residents recognized the social benefits of having automobiles for commuting, but were outrage by the dreadful social impacts of auto ownership:

"No one questions the use of the auto for transporting groceries, getting to one's place of work or to the golf course, or in place of the porch for "cooling off after supper" on a hot summer evening; however much the activities concerned with getting a living may be altered by the fact that a factory can draw from workmen within a radius of forty-five miles, or however much old labor union men resent the intrusion of this new alternate way of spending an evening, these things are hardly major issues. But when auto riding tends to replace the traditional call in the family parlor as a way of approach between the unmarried, "the home is endangered", and all-day Sunday motor trips are a "threat against the church;" it is in the activities concerned with the home and religion that the automobile occasions the greatest emotional conflicts."[4]

In the United States, social impacts must be considered as part of the process required for environmental impact assessment. A set of principles and guidelines for social impact assessment was developed by the Interorganizational Committee on Principles and Guidelines for Social Impact Assessment (ICPGSIA), a group of social scientists who sought to help public agencies and private organizations in carrying out responsible social impact assessment (SIA). Their motivation was that "SIAs help the affected community or communities and the agencies plan for social change resulting from a proposed action or bring forward information leading to the reasons not to carry out the proposal."[5] Like the environmental impact assessment, a major purpose for the SIA is to provide a mechanism for understanding and responding to the potential negative impacts of proposed policies, programs or projects.

> *By social impacts, we mean the consequences to human populations of any public or private actions that alter the ways in which people live, work, play, relate to one another, organize to meet their needs and generally cope as members of society. The term also includes cultural impacts involving changes to the norms, values, and beliefs that guide and rationalize their cognition of themselves and their society.*
>
> The Interorganizational Committee on Principles and Guidelines for Social Impact Assessment

This group defined social impacts and identified six principles for social impact assessment. The first principle calls for identifying the people who will be affected by the proposed action and collecting information about their social conditions so as to establish a base line for evaluating changes to those conditions. The second principle is that the analysis should be focused on the most important social and cultural issues that are likely to be affected. The SIA need not address every possible social or cultural impact that might be imagined. The third principle emphasizes the need for using proper methods and input from the public in identifying and quantifying problems that might be encountered. In other words, social scientists know how to do this kind of analysis, and they should be involved early in the design and evaluation process for major projects. The fourth principle establishes the role of the SIA as providing information to be used by decision makers and the public; the SIA and the people conducting the SIA are not the ones who ultimately make decisions about whether or not to go ahead with the project.

The fifth principle deals with environmental justice, which refers to the sometimes commonly used approach to locating or structuring projects: "locate them in the poorest neighborhoods and don't worry about how the disadvantaged will be hurt by the project." Who benefits and who pays are important considerations in SIA and in project evaluation in general. The final principal indicates that SIA doesn't end when the project or program or policy is implemented. It is necessary to monitor what happens to ensure that mitigation measures are actually implemented and to ensure that unforeseen social impacts will be recognized.

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[4] Robert S. and Helen Merrell Lynd, *Middletown: A study in Contemporary American Culture*, New York, 1929 [the authors spent more than a year in Muncie, Indiana, interviewing residents about all facets of life in that small city].
[5] The Interorganizational Committee on Principles and Guidelines for Social Impact Assessment, "Principles and guidelines for social impact assessment in the USA", **Impact Assessment and Project Appraisal,** Vol. 21 No. 3, Beech Tree Publishing, Guilford, Surrey, UK, September 2003

Predicted social impacts may be temporary or long-lived, and there may be minor impacts that affect a lot of people or intense impacts for a few people. To understand the importance of social impacts, it will help to consider the kinds of social impacts that might be encountered in typical infrastructure projects. Table 2 lists some of the notable types of impacts.

Table 2 Examples of Negative Social Impacts of Projects

Type of Impact	Examples
Relocation of people	• Entire villages displaced for the construction of a dam. • Hundreds of people and small businesses relocated to allow the construction of a highway through a city.
Deaths and injury during construction	• Deaths of more than 20,000 from tropical disease in the various efforts that eventually led to the Panama Canal. • Deaths resulting from workers falling off bridges or buildings in situations where safety nets were not installed.
Deaths, injury or illnesses resulting during normal operation of infrastructure	• Millions of people severely injured or killed in highway accidents • Bridges and tall buildings serving as jump-off points for suicides • Asthma and other illnesses resulting from air pollution caused by emissions from power plants, automobiles, or home heating • Tens of thousands of people injured or killed annually worldwide in grade crossing accidents between highway vehicles and trains
Deaths and injuries resulting from infrastructure failure	• Thousands of deaths and destruction of cities resulting from dam failures. • Loss of life from buildings and structures that collapse in earthquakes
Disruption of neighborhoods	• Limited access highways serving as barriers when they are constructed so as to divide urban neighborhoods. • Loss of property values following construction of large, noisy, or ugly buildings or infrastructure. • Creation of suburbs and decline of central cities following construction of better highways and policies that encouraged home ownership.
Loss of livelihood caused by negative environmental aspects of a project	• Destruction of fishing and shell-fishing areas following construction of bridges, port facilities, or oil spills • Decline in use of informal taxis and buses following opening of new subway lines in large cities in Latin America and Asia.
Loss of livelihood related to projects that help competitors	• Bankruptcy of canal companies following construction of railroads. • Bankruptcy of railroads following construction of highways and invention of cars, trucks and airplanes. • Decline in newspapers following widespread use of the internet.
Loss of privacy	• Disruption of the life of native peoples following construction of roads or railroads through their previously remote homelands.
Reduced quality of life	• Noise and dust resulting from construction of a highway • Shade resulting from construction of tall buildings

It might be even more helpful to consider some projects where the social impacts, whether foreseen or unforeseen, turned out to be devastating or reprehensible. If the leaders of the French company that set out to build the Panama Canal knew that tens of thousands would die in their failed attempt, would they have ever begun the project? If city officials in New Orleans had long ago understood the risks posed by hurricanes, would they have allowed housing to be built in the lowest-lying areas of the city? If automobile manufacturers, highway engineers, and government officials truly understood the dangers of automobiles (hundreds of thousands killed worldwide each year), would we have the system that we have today? These questions are worth some discussion. Hindsight may suggest that we would have done things differently if we had only known – but maybe the drive for a route to the Pacific, the need for more housing, and our great love affair with the automobile would have led us exactly to where we ended up.

Various researchers and agencies have used different categories of social impacts, and it is possible to construct quite elaborate topologies of social impacts. Whatever the categories, the main concern for the SIA will be to determine who is going to be hurt by the project or program, when will problems arise, and what can be done about them. As with environmental impact assessment, it is believed that there is much to be gained simply requiring these questions to be asked, with the answers and supporting information made public. If the problem is understood, then it may be possible to take action.

There broad categories of actions can be identified

- Adjust the design so as to avoid or reduce the social impacts
- Require mitigation as a condition for approval of the project
- Compensate those who are hurt by the project.

Whether or not any or all of these are necessary is something that will ultimately be decided by those who are threatened, local governments, developers, other stakeholders, and the courts.

Safety and Security

Safety and security are particularly important and emotional social concerns. Public reactions to projects seldom derive from a calm, rational assessment of the costs and benefits. Sometimes the public response is driven by fears and emotions, whether the fears relate to the potential for disaster or for national security. Proponents are likely to downplay the potential problems, while opponents are likely to stir up people's emotions. The classic case is nuclear power. While there have been only a very few serious accidents involving nuclear power plants in the U.S., the public has been very fearful of such accidents and very leery of proposals for sequestering nuclear waste. If nuclear power plants are built to modern safety standards, and if radioactive waste is properly sequestered, then they would seem to provide an efficient, clean alternative to the use of fossil fuels for generating electricity. However, public fears have forced extraordinary measures to be taken to limit the risks of such plants, and some countries have banned such plants altogether.

In the United States, a rather inconsequential incident at the Three-Mile Island Power Plant in 1979 was "the most serious in U.S. commercial nuclear power plant operating history, even though it led to no deaths or injuries to plant workers or members of the nearby community."[6] The accident led to very little off-site release of radiation. The average dose (1 millirem) of radiation to the population of 2 million closest to the site was only one-sixth of the dose received during a full set of chest x-rays. In addition, the NRC reports that studies have determined that there were no more than negligible effects on the environment. However, the accident at Three Mile Island led to sweeping changes in the regulation of the nuclear industry, including the addition of many costly safety procedures. The negative media attention that it received also created a terrible public image for the nuclear power industry as a whole, and no new plants were built in the US for 30 years. Acceptance of nuclear power varied widely in other countries. In Germany, public opposition led to a political decision in 2003 to phase-out of nuclear power plants, but in France, nuclear power had by then become the dominant source of electrical power.[7]

[6] Fact Sheet on the Accident at Three Mile Island. 1 Mar. 2004. United States Nuclear Regulatory Commission. 10 Nov. 2004. < http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html>
[7] Stephen Graham, "Germany begins nuclear phaseout," The Boston Globe, November 15, 2003

Summary and Discussion

The public sector's perspective regarding projects differs in several important ways from that of the private sector. Entrepreneurs view projects as a means of making their fortune; investors view projects as a way to earn a return on their investment; public officials and charitable organizations view projects as a way to achieve goals related to society's needs or desires. Many of the differences can be captured by the distinctions between financial analysis and economic analysis. Financial analysis addresses cash flows, whereas economic analysis also considers safety and security, growth in the economy, and provision of education, infrastructure, and other public services.

Another difference between the public and private perspective is that environmental and social concerns are more likely to motivate public projects, whereas such concerns are apt to be constraints on private projects. This is not an absolute difference. In particular, many infrastructure projects may have very negative consequences on the environment or upon people who live near project or who must move to accommodate the projects. Construction of roads through cities, creation of dams that displace thousands of people, irrigation projects that require flooding of fertile valleys, and use of public land for forestry and mining are examples of public efforts that can lead to serious controversy among agencies and among those who favor or oppose the projects. When controversies arise about public projects, a change in government, legal battles, or the passage of new legislation may be needed to resolve the issues. When controversies arise with respect to the social or environmental impacts of private projects, there could be legal and legislative battles to determine what kinds of activities are allowed and what kinds are prohibited.

A principle underlying public projects is that the benefits should exceed the costs. The project itself does not have to produce the cash necessary to cover the investment or even the operating costs, as the government has the power to raise taxes to pay for projects. However, the project should provide measurable economic benefits that are at least as great as all of the economic costs of the project. Just as the benefits can be more than the cash flow directly related to the projects, the costs can include social, economic and environmental impacts that are directly or indirectly related to the project. The logic underlying benefit/cost analysis can easily be misinterpreted. The proper interpretation of this kind of analysis is that the government should not pursue projects if the expected benefits are less than the expected costs. This does not mean that projects where benefits exceed costs should be approved, it only means that they deserve further consideration. Many controversies about the need for projects boil down to controversies as to what counts as a benefit, what counts as a cost, and how values should be put on factors such as safety, air quality, or job creation.

The extent to which concerns about environmental impacts, social impacts, or safety should affect the design or implementation of a project is something that will ultimately be decided by governments, developers, other stakeholders, and the courts. Over time, as the validity and magnitude of such concerns become clearer, it may be desirable or necessary to require improvements to existing infrastructure and develop more stringent regulations for locating, designing, and constructing new projects.

This essay has addressed the key factors that must be considered in enhancing the sustainability of infrastructure systems: financial feasibility, economic impact, environmental impact, and social impacts including safety and security. Finances are important, because cash will be needed to construct, maintain and operate infrastructure. Economic impacts are important, because they include many types of short- and long-term impacts that can help to justify a good project or to prevent a bad project. Environmental impacts are important, because an infrastructure-system that is too destructive to the environment or that requires excessive use of limited natural resources will not long endure. Social impacts are important, because it is ultimately society that decides whether or not to proceed with infrastructure projects and that bears the brunt of failures to consider hidden costs of projects.

It is clear that there are many diverse factors that will influence what needs are addressed, what projects are considered, and how projects will be evaluated. There will be no easy methods for determining the best projects, and no simple ways to gain public support for a particular project, although various methods and concepts can be used in reaching a consensus about what is needed and what should be done.

Comparing Strategies for Improving System Performance

> *"The basic idea is to define alternatives to just sufficient a level of detail to allow different stakeholders to at least rank order them in terms of desirability according to each identified criterion."*
>
> Theodor J. Stewart, "Thirsting for Consensus"

Introduction

Any major project is likely to have multiple objectives and measures of performance, especially but not only when public agencies are involved. Comparing strategies for improving system performance may at times be a straightforward matter of comparing financial costs and benefits, but it will be much more likely that important factors will be difficult or impossible to express in monetary terms. That is why project evaluation often focuses on cost effectiveness and why weighting schemes are commonly used when evaluating competing options.

The benefit of stating all costs and benefits in monetary terms is obvious: the methods used to compare financial costs and benefits can then be used to compare all of the economic costs and benefits. The danger of trying to state all costs and benefits in monetary terms is that the evaluation may simply disregard important measures that cannot be converted into monetary measures. The fact that it is difficult to put a price tag on beauty or equity is no reason to ignore aesthetics or to forget about being fair.

Discounting and Net Present Values

For some projects, it is possible to translate costs and benefits into monetary terms. At times, the translation can be straightforward, as when measuring changes in congestion by using the average values of time for the automobiles and trucks that are stuck in traffic. Other factors, such as safety, may require potentially controversial assumptions, e.g. the value to society of avoiding or incurring injuries or fatalities. Still others, such as aesthetics, can only with great difficulty be given a monetary value. Economists and other researchers have been very creative in developing methods of estimating the value of changes in measures that at first glance appear to be purely qualitative. For example, it is possible to link air quality to health and also to more mundane matters such as the need for window-washing and periodic cleaning of buildings.

Even if we can state the most important types of costs and benefits in monetary terms, we still have a problem in comparing options, since costs and benefits of an infrastructure project are likely to be spread across a period of many years or decades. The basic question is whether or not the expected future benefits will be sufficient to justify the initial investment. To answer this question, it is necessary to compare current and future costs and benefits. For any cost or benefit that can be monetarized, a process known as **discounting** can be used. Discounting provides a means of reducing future costs or benefits so that they can be expressed as equivalent **present values** that will be directly comparable to current costs and benefits. Discounting is used in both the public and the private sectors, with the public sector considering broad categories of costs and benefits and the private sector concentrating on cash flows. .

Discounting is necessary because money in the future is worth less than it is today or, to say the same thing in different terms, money today can be invested and grow into a larger sum in the future. The basic relationship between present and future value is a function of the discount rate r and the time period t:

(Eq. 1) $\text{Present value} = \text{Future Value}/(1+r)^t$

By use of this equation, future costs or benefits can be discounted to be equivalent to a current cost or benefit. For example, if an expected benefit of $1 million in year 4 were discounted at a rate of 5% per year, it would be worth only $822,000 today. The higher the discount rate, the lower the present value of a future sum of money. The same $1 million in year 4 would be worth less than $700 thousand today if it were discounted at 10%.

The **net present value (NPV)** of a project is the sum of the discounted values of all the benefits and costs associated with the project. If the NPV is positive, then the benefits outweigh the costs; if the NPV is negative, then the costs outweigh the benefits. Maximizing NPV may be viewed as the primary objective of a project, particularly in the private sector. In the public sector, this objective corresponds to maximizing the overall net benefits to society, taking into account any and all costs and benefits that can be expressed in terms of dollars and cents. If only financial costs are considered, as would commonly be the case in the private sector, then this objective would be stated as "maximize the net present value of cash flows".

The choice of a discount rate is an important factor in project evaluation. A very high discount rate will emphasize initial costs and make it more difficult to justify projects that require large investments; a very low discount rate will favor projects that have net benefits that continue over a very long time horizon. Private companies typically use a discount rate of 10% or greater in evaluating their projects; higher rates are used if projects are perceived to be riskier. Public agencies, which do not have to pay taxes, will typically use a lower discount rate. Discount rates will rise with inflation in both the private and public sectors.

This section has only introduced the most basic concepts of discounting and NPV, but even these basic concepts are very powerful. If we are given costs and benefits that occur over any stretch of time, and if we have a discount rate, we now know how to calculate the NPV of these benefits.

Measuring Cost effectiveness

It is always possible to calculate the cost effectiveness of any investment with respect to any non-financial, but quantifiable objective. Cost effectiveness is the ratio of the investment cost to the improvement in the measurement of interest, i.e. the $ per unit improvement. If different options are compared, the most cost effective option will have the lowest cost per unit of improvement.

Consider the case shown in Table 1, where there are three alternatives for reducing the impact of highway noise on the residents of two new apartment buildings that will be built adjacent to a heavily traveled interstate highway. The first option is to erect a quarter-mile long sound barrier along the edge of the property that abuts the highway. The second option is to require special sound-proofing for all of the windows and walls that face the highway. The third option is to design floor plans to minimize the windows on the walls facing the highway, e.g. by placing bathrooms, closets, and stairways along that wall. The effectiveness of each measure is estimated in terms of the average reduction in noise levels that would be experienced by residents living in the structure. In this hypothetical example, the three strategies result in a similar reduction in noise levels, and redesigning the floor space is the most cost-effective way to gain peace and quiet.

Table 1 Cost Effectiveness of Three Options for Reducing Noise Levels

Option	Cost	Reduction in Noise Levels	Cost-Effectiveness ($/% improvement)
Noise barrier	$500,000	20%	$25 thousand
Sound-proofing	$200,000	22%	$9.1 thousand
Redesign floor space	$100,000	21%	$4.8 thousand

Using Weighting Schemes in Multi-Criteria Decision-Making

Any major project, but especially public projects, will be trying to satisfy multiple objectives, many of which will be non-financial. There are likely to be many competing designs, some of which are markedly different in approach. Each of these projects can be evaluated in terms of each of the objectives, producing a (very large) matrix showing the predicted impacts of each option on each of the objectives. It is very unlikely that any option will be rated best on all measures; instead, one design will be the cheapest, another will have the highest capacity, another will have the least impact on the environment, and another will be the easiest to construct. Which alternative is the best is dependent upon how much weight is placed on each objective.

Choosing the best project will therefore ultimately require making judgments concerning the relative importance of the various objectives and the validity and uncertainty of the evaluation process. Unless there is a single individual with authority to make all design decisions, selecting the best project will inherently be a political process: people with different perspectives and agendas will have to work out a process to determine the best way to proceed.

There are many methods that can be used to help structure the political process. Weighting schemes can be developed and applied to each of the criteria. However, weighting schemes may appear to be more objective than they really are. This is not an argument against using weights, and it is certainly not an argument against having multiple criteria. However, it is a caution to avoid thinking that it will be easy to agree upon criteria or weights or to think that the public will agree with whatever criteria or weights are proposed by any of the parties.

Choosing weights is simply another way of making judgments. In situations where there is general agreement concerning a) the options to be considered, b) the relevant criteria, and c) the relative importance of the criteria, a structured weighting scheme can be helpful in ranking the options. However, weighting schemes will not be of much use if there is strong disagreement about which alternatives should be considered, which criteria are most important, and how impacts should be measured. Presenting a weighting scheme as a way to obtain an "objective ranking of the options" will, in such cases, be impossible, as the different groups will simply push for weights that favor their own preferred options. Difficulties in reaching consensus will be exacerbated if many of the criteria are highly qualitative.

The role of the analyst is clear: provide the best information possible within the available time and budget; identify what is certain, what is likely, and what is possible. Let people know how much faith you put in each part of the analysis. Explain the assumptions, and indicate whether or not you or your expert colleagues believe such assumptions to be reasonable. Where have you had to make guesses, say where those guesses are most uncertain. You also want to make sure that the range of options is wide enough to cover the major strategies that might be considered. Finally, in public meetings or in private meetings with stakeholders, you can try to ensure that the discussion deals with the actual data and credible options, and you can try to provide insight as to the cost-effectiveness of various proposals with respect to various criteria.

Seeking Public Input

Input from the public and key stakeholders can be helpful in identifying how to look at a complex problem. Input will be most helpful – and the exercise is likely to be most productive – at a point in time when there is general awareness that something needs to be done about a problem, but no one knows (or thinks they know) what is best to do. The main reasons for seeking input from the public and from stakeholders are to clarify the nature of the problem, to identify potential alternatives or strategies for dealing with the problem, and to discuss the relevant criteria for selecting and evaluating specific alternatives. Preliminary discussions can also be very useful in identifying where there is consensus about needs and opportunities, where additional information is needed, and where potential controversy will be most likely. This feedback will be helpful in allocating research and planning resources and in determining how best to structure the process.

For example, many projects are aimed at promoting development while at the same time improving living conditions for people living in a region and protecting the environment. Different groups of people would likely place much different weights on the costs and benefits related to such things as regional development, median income for residents, pollution, and loss of open space. Possible types of projects might include investments in new infrastructure, upgrading technology, providing regulatory incentives, increasing awareness of best practices, or changing governmental structure or policies. Input from citizens could help prioritize the problems and place weights on various costs and measures, thereby providing a framework for seeking the most effective strategies. Consultants could conduct workshops on the issues and facilitate discussions among people representing a wide range of interests and expertise. An informed examination of the needs, problems, and strategies for dealing with them may lead to approaches and projects that are less controversial, more responsive to the needs of the region, and better for the environment.

Summary

Large projects will always be trying to meet multiple, sometimes conflicting objectives. Sometimes there will be obvious ways to define economic or financial criteria that capture the essence of a project. More often, it will be necessary to make assumptions concerning the monetary value that might be associated with some of the impacts of a project. And there may be times when the problems and potential solutions are primarily concerned with factors such as aesthetics or equity that are inherently difficult to quantify.

<u>Expressing Costs and Benefits in Monetary Terms</u>

If the most important objectives can be expressed in economic terms, then it will be possible to create a single monetary estimate of the costs and benefits associated with a project. Many private sector projects are primarily concerned with financial matters: if this project proceeds, will the revenues be sufficient to cover the investment and operating costs? Many public projects will be concerned with broader economic benefits, such as economic growth, job creation, and average income. While these economic benefits are not necessarily readily tied to the project or to specific individuals, they can certainly be expressed in monetary terms.

<u>Comparing Present and Future Costs and Benefits</u>
When evaluating costs and benefits over the life of a project, it is necessary to discount future costs and benefits for comparison with present costs and benefits. By using a discount rate, any future cost or benefit can be reduced to an equivalent present value. By summing all of the discounted costs and benefits, it is possible to obtain the net present value (NPV) of a project. If the NPV is positive, then the project provides net benefits and may be worth pursuing.

<u>Cost Effectiveness</u>

Cost-effectiveness is a very useful concept when dealing with criteria that are quantifiable but difficult to monetarize. Cost-effectiveness is the ratio of the cost of a proposed project to the change in performance. So long as it is possible to quantify a key aspect of performance, such as risk or capacity or service quality, it should be possible to evaluate alternatives by considering their cost-effectiveness in improving this aspect of performance. Cost-effectiveness will be less relevant in projects where there are multiple objectives, so that it is impossible to focus on just one critical aspect of performance.

<u>Weighting Schemes for Projects with Multiple Criteria</u>

When there are multiple objectives, some of which cannot be monetarized, then the evaluation cannot focus on a single metric. Instead, some kind of weighting scheme – whether objective or subjective - will have to be used to compare alternatives. If a decision is made by an individual or by the vote of a committee or by a referendum, then each person involved can make their own subjective judgment in determining their preferred option. Often there will be a structured process for making the decision that requires participants to consider multiple options, to consider impacts upon various objectives, and to follow a specific procedure for ranking the options. If so, then some sort of a weighting scheme may be helpful. With a weighting scheme, it is possible to collapse any set of multiple measures into a single measure of effectiveness.

It is critical to remember that there is no objective way to determine the "correct" weighting scheme or even the selection of the "proper" criteria. The choices of what criteria to consider and how much weight to give to each one could cause intense debate among those trying to address a problem or those trying to promote a particular project.

Using Public Input in Identifying and Evaluating Projects

Input from the public and/or stakeholders can be helpful in identifying and evaluating projects. Public input can help in clarifying the nature of the needs or problem, as well as in identifying measures or criteria that can be used to define the problem and to evaluate potential solutions. In some cases, very rough measures of potential impacts may be useful in reaching consensus about what to do, how to do it, and when to begin.

Public Private Partnerships

Well-structured and well-implemented PPPs offer the prospect of efficiency gains in the construction of infrastructure assets and the provision of infrastructure-based services and, therefore, also lower the government's costs in making these services available.[1]

Introduction

Public agencies, developers, companies, investors, and the general public have different perspectives on projects. The public sector is much more focused on identifying and satisfying public needs, whereas the private sector is much more concerned with achieving financial benefits. The public sector is led by elected officials who must justify their actions and decisions to voters, and these officials are involved in many aspects of society, from education to provisions of parks to water resources and waste management. The division of labor in the private sector produces leaders who are much more sharply focused on specific problems or types of activities. Some are concerned with finance, others with planning and design, and others with operations and management of specific types of infrastructure or industries. The public sector has the ability to raise money from taxation and, at the national level, to adjust the supply of money and the availability of credit for financing projects. The private sector offers entrepreneurs a chance to get rich by designing, promoting, constructing and operating particular projects. Elaborate systems have evolved that enable developers to obtain the funds necessary to build projects, and people or companies who are willing to take risks have a chance to achieve great rewards. The public sector has the ability to guide development through tax policy, zoning, building codes, and provision of infrastructure. The public sector also has the responsibility for public heath, public safety, and environmental protection. People who are successful in the public sector have a chance to attain great influence over policy and development.

There are few if any projects that do not require some sort of cooperation between the public sector and the private sector. Even a small addition to your house or the construction of a dock for your boat will require a building permit and perhaps a wetlands permit, while construction of any large building will only be possible if the developer secures numerous approvals from various government agencies related to the location, design, construction materials, and construction processes. Likewise, when a government agency sets out to build a school or a road, that agency will typically employ private sector contractors and sub-contractors. These interactions between the public and private sector do not constitute a partnership. Building a house or a dock or an office building is clearly a private project, even though it must be sanctioned by government and follows rules and regulations specified by law. Likewise, building a school or a road is clearly a public project; even though the work is actually done by the private sector, the project is defined and funded by the public sector.

Figure 1 summarizes what is needed to have a successful project in the private sector. First, the decision to proceed will depend upon having a positive net present value (NPV) or an internal rate of return (IRR) that exceeds the company's hurdle rate for new investment. The project will then need to have regulatory approvals, which could relate to zoning, environmental impact assessment, site management, building codes, and any other regulations that are mandated. If financing is available, and if the company has access to the resources and managerial expertise to manage the project, it can proceed to implementation. But that is just the beginning. Whether or not the project is successful depends at first upon the ability to complete the project as designed, within the specified budget, and on schedule. Once the project is completed, ultimate success will depend upon the way that it is utilized; in particular, it must function safely and efficiently, and it must generate revenues that will eventually be sufficient to cover both operating and investment costs.

[1] Bernardin Akitoby, Richard Hemming, and Gard Schwartz, *Public Investment and Public-Private Partnerships,* International Monetary Fund, Washington D.C. 2007, p. 9

Figure 1 Overview of the Private Sector's View of a Successful Project

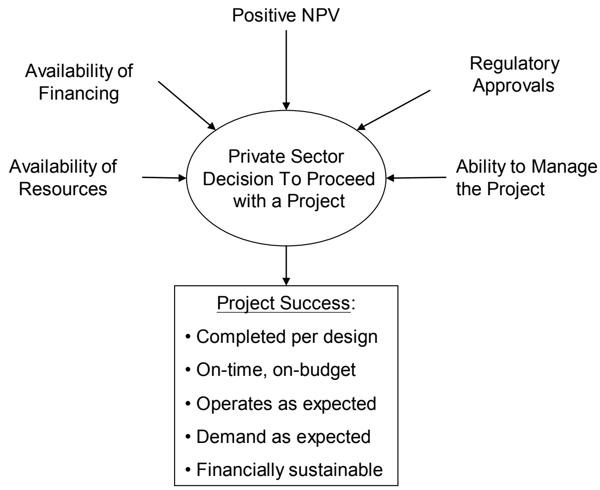


Figure 2 illustrates the broader perspective of a public agency. The first major difference is that the project can no longer be considered merely as a financial effort. Instead, economic, environmental, and social impacts must be considered and incorporated within a benefit/cost analysis. If taxpayers are willing to support a project because of economic or other benefits, then taxes can cover some of the costs and the project does not require a positive NPV. The public sector will face similar regulations regarding land use and environmental impact assessment, but there is a major difference. Laws and regulations can be used to limit or restrict what either a private company or a public agency might do, but political actions can defeat proposed public projects. A private project must meet the regulations, but a public project must also satisfy the elected officials and ultimately the public. The second major difference is that the definition of success is much broader, because economic, social, and environmental factors will also be of direct interest to a public agency. To sustain a project over the long term, especially if tax dollars are required to support operations, public officials and the public must be convinced that those tax dollars are worth spending.

Reasons for Considering a Public Private Partnership

Public/private partnerships arise when a public agency or agencies work with the private sector on a project to build, finance, and/or operate a facility. The public and private sectors are partners because they share in the risks and rewards of the project, and they share in the design and ownership of the project.

Some public/private partnerships arise in order to take advantage of the differing strengths of the two sectors. Table 1 compares some of the strengths of the public and the private sector as related to the implementation of infrastructure projects. Broadly speaking, the public sector must be more concerned with social, economic and environmental issues, while the private sector is more concerned with finance. The public sector has greater ability to identify public needs and to allocate funds to address those needs in a reasonably fair manner; the private sector can quickly respond to perceived needs, without worrying so much about what is fair or what is most important to society as a whole. The public sector can raise money via taxes and the sale of low-interest bonds, and it has real powers related to land use. The private sector can raise money from investors, and it can obtain very large sums for clearly profitable projects. The comparisons could go on and on. Some people would add that the private sector is more efficient or more honest, but there are certainly examples of very efficient and inefficient operations in both sectors, just as honesty, wisdom, fraud and foolishness can be found in both. The point is that the two sectors have different strengths and there are some projects that will be better designed, constructed, and operated if the two sectors work together.

Figu **roject**

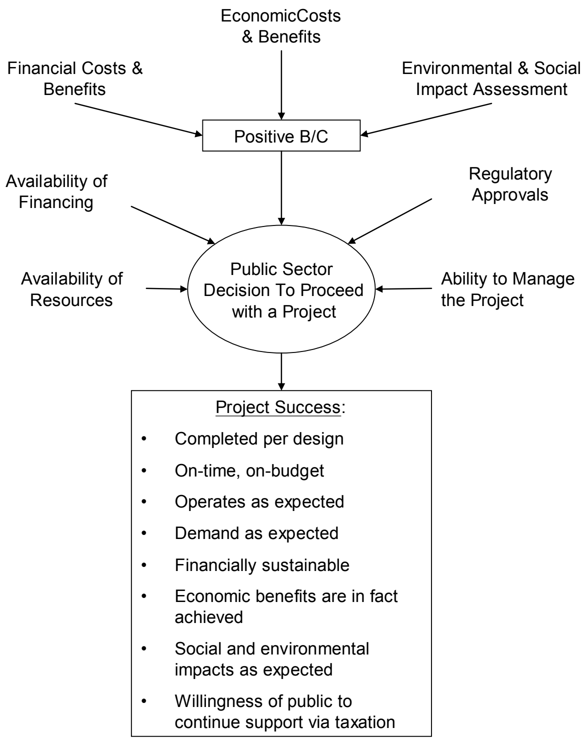
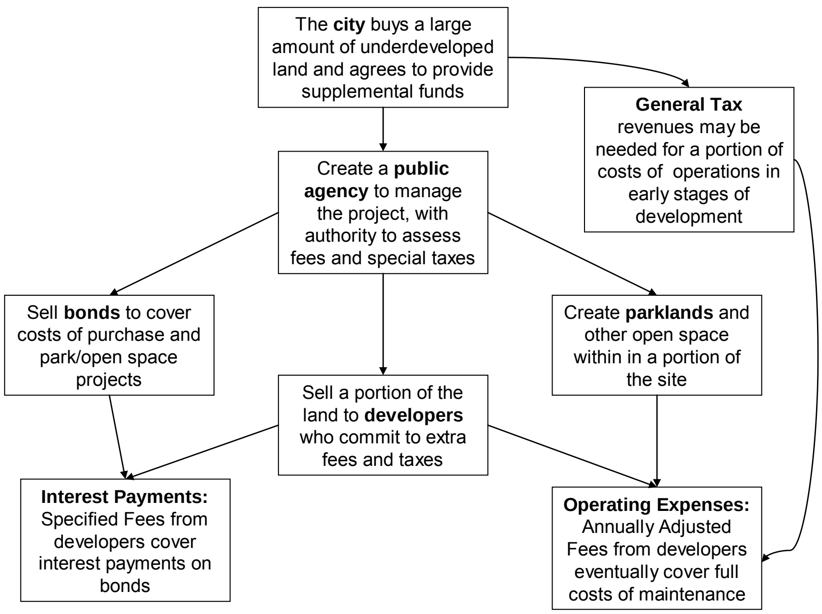


Table 1 Complementary Strengths of Public and Private Sector

Area	Public Sector Strengths	Private Sector Strengths
Identifying societal needs	Political process can establish priorities among competing needs	Private firms can respond quickly to perceived opportunities
Design	Establishment of building codes and construction standards	Development of new techniques or designs
Construction	A stable work force can be assembled for continuing needs, such as road maintenance	Numerous companies exist or can be created for all types of construction
Finance	Access to tax revenues and ability to issue bonds with low (possibly tax-free) interest rates; possible difficulties in raising fees to keep pace with inflation	Ability to raise capital for projects; recognizing the level of risk involved; greater freedom in raising fees to keep pace with inflation
Politics	Political approval may require more complete assessment of alternatives and a fairer distribution of costs and benefits	Insulation from politics may result in more objective assessment of projects
Land Use	Able to assemble large tracts of land for public purposes using eminent domain	Owners can use their land any way they like, so long as zoning and other regulations are followed
Labor	May be required to use local labor or union labor, resulting in higher costs for construction or operation	May be able to use more efficient procedures or non-union labor, resulting in cheaper construction

Sometimes a PPP is pursued in order to take advantage of the relative strengths of each party. For example, the City of Tempe, Arizona needed better flood control, it wanted to clean up an area largely used for waste disposal, and it hoped to encourage economic development.[2] An innovative arrangement was developed whereby the city assembled a large parcel of land around the Salt River; they then re-zoned the land for higher density development and sold plots to developers with the stipulation that they would pay special fees and taxes that would ultimately pay for the creation of a 5-mile long lake and extensive park land. The combination of open space and nearby high-density development achieved substantial public benefits, while developers had the opportunity to make profits that were based upon the proximity of their land to what would become a very attractive site. Tempe's experience shows how investment in public space can be financed through a combination of taxes and fees targeted to those who will most benefit from being close to the open space and those who will be attracted to the area because of the open space. Coordinating flood control, recreation, waste removal and habitat restoration allowed tremendous improvements in what was previously a rather derelict portion of the city. The financing for the project was been very successful and could serve as a template for similar investments in other cities (Figure 3). One potential problem with this project is that it led to a continuing demand for water, because of evaporation, and water supply could become an ever increasing concern in that region of the country. Other options could have been considered that would have needed much less water, such as having a landscaped region surrounding a small creek or restoring the area to its original desert habitat.

Figure 3 Outline of the Financing for the Tempe Town Lake Project



A second reason for public/private partnerships is that there are significant public and private benefits for a potential project. Taken together, the benefits might be enough to justify the project, while neither the public nor the private sector may be willing to tackle the project on their own. In Kansas City, private railroads worked with public agencies to construct a flyover, which is a railroad bridge that takes one rail line over another rail line. The railroad benefited because the north-south trains no longer interfered with the east-west trains, while the city and its residents benefited because delays at rail-highway grade crossings were eliminated or sharply reduced. Public financing reduced the costs of the project, while per car fees collected from the railroads will eventually pay for their portion of the project.

[2] Tempe's website has sections devoted to the history and management of the Tempe Town Lake (www.tempe.gov/lake).

A third reason for a PPP is that the public sector wishes to maximize its ability to undertake projects by gaining access to the financial markets. The ability of a government agency to raise money may be limited by budgets or by the credit rating of the agency, or a government may be unable to use its assets as collateral to raise money. The government can retain control over the design and location of infrastructure, while leasing or selling facilities to a private company. The financing of the project can be based upon fees that are related to the operation of the facility.

For example, the City of Toronto built a toll road that by-passes a portion of their downtown, and they wished to extend this road. Since they did not want to issue bonds or raise taxes to pay for the road, they decided to sell the road to a company that would operate it and extend it – at the company's expense. They sold the road for more than it had cost them to build it, and they thereby were able to have a private company extend the road with no further government expense.

A fourth reason for a public private partnership would be a government interest in assisting new industries. While the potential for economic potential may be evident, and there may be companies willing to undertake projects, the companies may be unable to secure financing. The government may then decide to assist the company by making loans or even by making an equity investment. For example, when the private sector was unable to raise the financing necessary to start off-shore oil drilling in Newfoundland, the provincial government decided to make a substantial investment in return for partial ownership of the new enterprise.

In summary, there are various reasons for PPP:

- **Complementary strengths**: the partnership builds upon the complementary strengths of the public and private sectors to complete a project that could not be undertaken – or done as well – by either sector.
- **Public and private benefits**: the partnership is created because the project has substantial public and private benefits, and cooperation allows both the public and private sector to satisfy their objectives more effectively that they could by acting alone.
- **Expanded public capabilities**: the partnership allows private capital to be accessed for undertaking public projects.
- **Economic development**: the partnership is created in order to exploit opportunities for economic development that will ultimately be profitable for the private sector while increasing jobs and economic activity within the region.

As illustrated by Figure 4, the overall structure of a PPP must incorporate all of the elements that are of importance to either sector. The private sector still seeks a positive NPV and successful completion and operation of its portion of the project. The public sector still seeks a positive ratio of benefits to cost and successful completion and operation of its portion of the project, with negative social and environmental impacts no worse than anticipated. Both sides of the partnership will need to be satisfied and financially successful if the project is to be a long-term success.

Principles of Public Private Partnerships

The most important principle of public private partnerships is that **each side must bear an appropriate portion of the cost, benefits, and risks.** Private companies are unwilling to increase their investment in projects in order to provide public benefits. Public agencies are unwilling to make investments unless there is a sufficient public benefit. Private companies will be concerned with financial performance, i.e. cash flows, profitability, and return on investment. Public agencies will be concerned with cash flow only to the extent that cash is needed to implement a project; they may be willing to make substantial investments that are justified by socio-economic benefits, such as an increase in economic activity or new jobs, reduction in congestion, or improvement in the environment or in public health.

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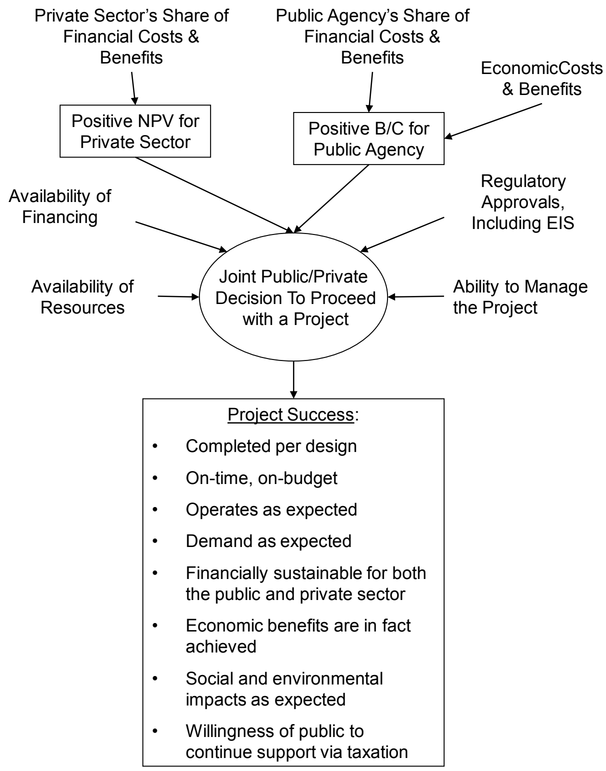


A second principle for private companies is that **each project is a separate case**. Just because they cooperate with a public agency in one project, they do not want to be forced to cooperate with that agency or other agencies on similar projects or other types of projects in the future.

A third principle is that **the partnership should be designed to deal with a particular situation**, since public participation can take many forms:

- Financial input and ownership.
- Leasing publicly constructed facilities.
- Authorizing private construction and operation of a facility that will ultimately revert to the government after a specified period.

Which form of participation is most appropriate will depend upon the circumstances and the aims and capabilities of both the public and private partners. What was best in one situation is not necessarily what should be used in a subsequent situation.

Creating a Framework for a Partnership

For parties to come together in a partnership, all parties must perceive that their potential benefits justify the costs and risks that they incur. As in creating any partnership, negotiation is possible and necessary. Key questions will include the following:

- Who pays how much for what portion of the project?
- What risks are accepted by each partner?

- Who controls design?
- Who controls construction?
- Who controls operations?
- Who owns what portion of the project?
- Will ownership of the project change over the life of the project?

The key differences in the public and private perspectives will include the following:

- Financial vs. economic return:
    - The private sector requires a minimum level of financial performance, but the public agency may seek economic benefits such as relief of congestion, potential for development, jobs, and increases in regional product.

- Cost of capital and access to capital
    - The cost of capital will generally be much greater for the private sector than for the public sector. The public sector can raise funds by selling government-guaranteed tax free-bonds that may have very low interest rates, assuming that the government agency has a good credit rating.
    - The private sector can raise funds for risky projects by selling stock, thereby giving investors partial ownership in the company and a chance to make a great deal of money if the project succeeds – as well as a chance to lose everything if the project fails.
    - The financial markets recognize and accept the possibility that a project will not be successful and that companies may be forced into bankruptcy; it is possible and not unusual for companies to fail, but public agencies are expected to endure despite failure.

- Institutional and organizational flexibility
    - Public agencies control many of the policies and institutional requirements that constrain or limit a project; a public agency is likely to be in a better position to obtain approvals for such things as zoning variances, building permits, and environmental approvals, because the public agency will generally be viewed as working in the public interest.
    - Private companies will likely be more flexible in creating organizational structures to deal with the design, construction, and operation of projects, especially projects that would be much different or much larger than what the public agencies have been involved in.

- Time frame
    - The time frame of private companies is heavily influenced by the fact that discounting reduces present value of both positive and negative impacts that may occur in the distant future; public agencies a) typically have a lower discount rate and b) typically have ethical commitments, constitutional outlooks, and other factors that lead them to have a much greater concern for what happens in the very long run.

These four major differences in interests and perspective suggest ways that PPP can be productive. The role of the public agency may be designing the project so that it provides economic, social, or environmental benefits to the public, providing access to low-cost sources of capital, securing project approvals from the various agencies involved in the project, or ensuring that the project provides long-term positive benefits to the public. The role of the private sector may be designing the project so that it generates cash flows sufficient to justify the necessary investments, providing access to financial markets that are willing and able to provide funds for very large or somewhat uncertain projects, creating new organizations to help in designing, constructing and operating a project, and ensuring that the project does not take too long a time perspective.

Determining How Much to Invest in a PPP

The analysis of a potential PPP will be approached by each party using the tools and techniques that they would use for any other project. Each party will have to estimate the cash flows associated with the project, and the public agency will also have to estimate the economic, social and environmental costs and benefits that are expected.

The private partner will have to be satisfied that its NPV is likely to be positive or that its internal rate of return is likely to be acceptable, based upon reasonable assumptions about the factors that will influence the outcomes of the project. The private partner will not be interested in increasing its investment in order to allow greater public benefits, but may be willing to agree to a modified project so long as the public sector agrees to pay for any added costs.

Likewise, the public partner will have to be satisfied the benefit/cost ratio is adequate, based upon their perception of the possible outcomes of the project. Both the benefits and costs can include non-financial factors such as improvements in congestion or air quality or access to public services. They can also include the economic benefits for the regions, such as job creation or the impact on average income or gross regional product.

Each partner will be able to determine the maximum amount that they would be willing to contribute to the project; if the combined amounts that they are willing to pay exceed the cost of the project, then it is feasible. The parties will naturally try to find an arrangement where their actual contribution is less than what they are willing to pay, a process that could take some time. Note that it is not necessary for one party to explain its reasoning or to provide its assumptions about unit costs or expected outcomes to the other party. The negotiations can proceed based upon what each partner is willing to contribute and what arrangements are made for sharing the risks associated with the project.

Figure 5 suggests how a public agency might negotiate with private developers in order to create more housing that is affordable for low income residents. From the public agency's perspective, there are three key issues:

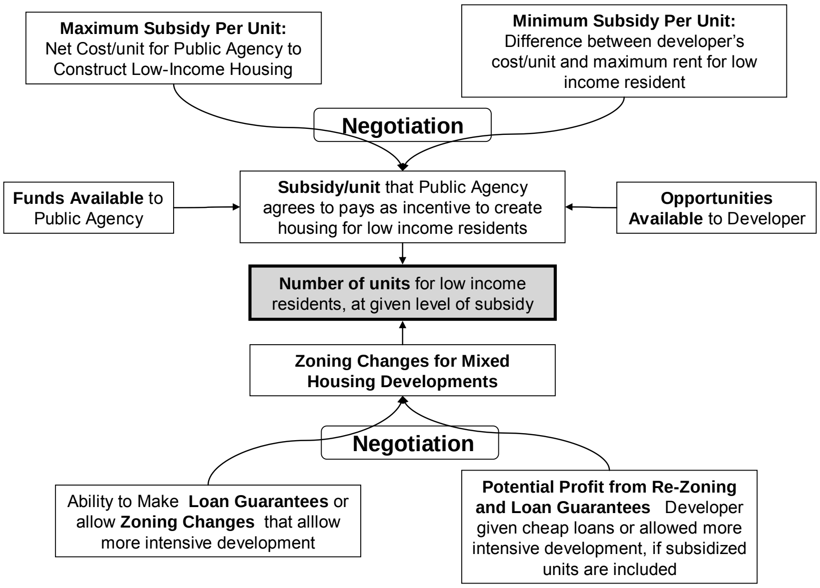
- The amount of money available for constructing or subsidizing housing for low-income residents.
- The cost/unit of constructing public housing for low-income residents, which places an upper limit on the subsidy/unit that they will be willing to pay.
- The feasibility of changing zoning rules to allow more intensive development, which will determine how much of an incentive can be offered to developers.
- The ability to guarantee the developer's loans if the developer agrees to reserve a certain number of units for low income residents.

From the developer's perspective, the key factors are:

- The cost per unit for construction, which must be covered by the combination of rent from the low income occupant and the subsidy from the public agency. This determines the minimum subsidy that they will accept.
- The ability to make more money if they are allowed to develop more units on a given plot of land, which would allow them to include more subsidized units or to reduce the minimum subsidy that they would require.
- Whether or not the benefits of lower interest rates are sufficient to offset the lost rents if some units are reserved for low income residents.
- Other opportunities for development: is it worth their while to negotiate or should they simply build what is currently allowed on the sites they own or consider projects in other locations?

Thus there will be two aspects to the negotiation. First, if the minimum subsidy that the developer will accept is less than the maximum that the public agency is willing to provide, then there could be a negotiated subsidy per unit. Second, if it is feasible to modify the zoning or offer loan guarantees, it would be possible for the developer to undertake more profitable development in return for including more units for low income residents.

Figure 5 Key Factors in Negotiating for Low-Income Housing



Example: Using a PPP to Maximize a City's Ability to Undertake Projects - Toronto's Highway 407[3]

By using a PPP, a government entity can capture the value of its infrastructure, while moving the burden for creating new infrastructure to the private sector. This example shows how the province of Ontario built a state-of-the-art highway, then leased it for 99 years to a private consortium for double what it had cost to build. The consortium even committed to extend the highway, at no cost to the city.

The story begins in 1994, when construction began on a 69-km fully automated toll road that would create another route through Toronto, thereby adding capacity to one of the most congested highway corridors in Canada. The Province of Ontario financed the C$1.5 billion project by selling taxable, general obligation bonds. The road opened in 1997, attracting 200,000 trips per day and annual revenues of C$70 million. Two years later, Ontario decided to privatize the road by leasing it to a private company that would agree to construct the planned 39-km extension, which was expected to cost C$0.5 billion.

The province asked for bids on the highway, assuming a 99-year lease. Since the value of the highway depended entirely upon the tolls that could be collected, certain restrictions were placed on tolls. The tolls were initially limited to 10 cents per mile for automobiles, with an increase to 13 cents per mile over 15 years plus adjustments for inflation. Tolls were two to three times higher for trucks. Beyond 15 years, there would be no limit on tolls so long as peak-hour traffic volumes exceeded 9,000 vehicles per hour. No limit was placed on the potential ROI for the successful bidder.

The winning bid was submitted by a consortium that agreed to a purchase price of C$3.1 billion for a 99-year lease, which was slightly more than double the construction cost of the first section of the highway. The company was required to maintain nearly $400 million of working capital, and they were required to keep C$775 million equity in

[3] Source: Traffic Technology International Journal, June/July 1999

the project. These restrictions limited the amount that the company could borrow, thereby limiting the risk of bankruptcy. The expected return on their investment was 11%.

The key issues in this deal concern the level of tolls, future volumes of traffic, and the role of this highway in the regional transportation system. By charging tolls, the highway operator captures some of the general economic benefits of the highway. Conceivably, a private company could maximize its profit by charging very high tolls, thereby enabling this highway to operate with little or no congestion, while traffic that could easily go on this route would shift to other, much more congested highways. Selling parts of the system could make it more difficult to manage the overall highway network effectively.

This example demonstrates a way for governments to tap the enormous value of public infrastructure. Ontario had built the road as part of its on-going program of highway construction. It built the road as a toll-road on the assumption that the tolls would be sufficient to cover the interest on the construction bonds, along with the expenses of operating the highway. They wanted to sell the road to a private company largely in order to move the debt associated with the road off the public accounts, thereby protecting or improving the province's credit rating. In fact, the deal did much more than takeover the debt associated with the highway: it provided an extra C$1.5 billion to the treasury and the winning bidder agreed to finance the next section of the road as well.

In the U.S., politicians in several states including Pennsylvania and New Jersey have considered similar projects, in which the rights to operate existing toll roads would be sold at auction. If the private operator is allowed to charge much higher tolls, then the toll roads could have a value far in excess of the original costs. Of course, similar financial benefits could be obtained if the states raised their own tolls, and that in fact is what happened in New Jersey.

Example: Using Public Investment to Stimulate the Economy - Investment in off-shore oil exploration by the Province of Newfoundland and Labrador

In 1979, after 16 years of research and exploration, oil was discovered in the Hibernia oil field located off the coast of Newfoundland, Canada. The high prices of oil at that time justified looking for oil offshore, even though the costs of offshore drilling are very high. Political disputes between the federal and provincial governments delayed exploitation of the oil field for more than a decade, as both claimed jurisdiction over the area.[4] After the political battles were settled, construction finally began in 1991 on an enormous platform and related infrastructure for extracting 150,000 barrels of crude oil per day.

The project was undertaken by a consortium of five oil companies along with a new government agency called the Canada Hibernia Holding Corporation that owned an 8.5% share in the project. The government participation in the project was designed to produce income for the Province of Newfoundland and Labrador, one of the poorest provinces of Canada. The construction and operation of the site plus additional energy-related jobs provided a major boost to provincial economy. There were 5,000 construction jobs, and the growth in the energy sector boosted the region's economic activity by 3.1% during the first year of operation.

[4] G.E. Bridges & Associates, "Due Diligence Issues Report", British Columbia Offshore Oil and Gas Socio-Economic Issue Papers, Royal Road University, Victoria BC, Canada May 2004

Summary

Motivation for Public Private Partnerships

The public and private sectors have differing types of objectives and complementary strengths in defining, financing, constructing and managing projects. Thus, there will be many situations where projects are likely to be better designed, constructed or operated if the two sectors work together. The public sector is structured so as to allocate resources among competing public needs, whereas the private sector is structured so as to achieve financial objectives. The public sector has the ability to raise funds via taxation or by issuing bonds backed by specific revenue sources (e.g. tolls or user fees), but for financial or political reasons may have limits upon the amount of money that can be raised for major infrastructure projects. The private sector has greater ability to attract investors for large projects that may be risky, but that have potential for high profits. The public sector has the power to impose and modify many of the laws and regulations that affect development, including zoning, other land use regulations, and environmental and social regulations. The public also has the power of eminent domain whereby a public agency may be able to force landowners to sell their land so that it can be used for a public purpose, such as a road, a dam, or a reservoir.

The public sector may have agencies devoted to certain types of infrastructure, such as highways and waterworks, but they may not have experienced employees capable of dealing with major new projects in important areas. Private companies with specialized skills will be able to apply those skills throughout the world. Private companies may also have greater experience and therefore greater efficiency in undertaking certain types of projects.

Creating a Partnership

Negotiation will be necessary to ensure that all parties to the agreement believe that their costs will justify the costs and the risks that they incur. The private sector will participate only if they perceive sufficient financial benefits. The public sector may in part be concerned with financial matters, but must be sure that the projected benefits - whether or not they are financial or economic benefits – are sufficient to justify whatever social and environmental costs and benefits may be incurred. The negotiations will consider design, financing, responsibility for construction management, responsibility for operations, and ownership. The risks include the usual risks associated with construction of and demand for a project. In addition, there will a question as to the extent to which the public and the private sector share the risks of financial failure: to what extent, if any, will the public sector be responsible for paying off bonds? The public sector will be able to accept long-term social and environmental benefits as justification for their participation, but the private sector will require more immediate financial benefits.

The analysis of a potential PPP will be approached by each party using the tools and techniques that they would use for any other project. Each party will have to estimate the cash flows associated with the project, and the public agency will also have to estimate the economic, social and environmental costs and benefits that are expected. The private partner will have to be satisfied that its NPV is likely to be positive or that its internal rate of return is likely to be acceptable, based upon reasonable assumptions about the factors that will influence the outcomes of the project. Likewise, the public partner will have to be satisfied the benefit/cost ratio is adequate, based upon their perception of the possible outcomes of the project. Each partner will be able to determine the maximum amount that they would be willing to contribute to the project; if the combined amounts that they are willing to pay exceed the cost of the project, then it is feasible. The parties will naturally try to find an arrangement where their actual contribution is less than what they are willing to pay, a process that could take some time.

Types of Public Private Partnerships

Four types of situations that are well-suited to the establishment of a public private partnership:

1. The project requires the complementary strengths of the public and private sector.
2. The project provides both public and private benefits, and only the combined benefits are large enough to justify the project.
3. The public sector wishes to maximize its ability to undertake projects by gaining access to the financial markets.
4. The public sector decides to assist new industries.

Evolution of Infrastructure-Based Systems

But it came to me then, I am sure, for the first time how promiscuous, how higgledy-piggeldy was the whole of that jumble of mines and homes, collieries and pot-bands, railway yards, canals, schools, forges and blast furnaces, churches, chapels, allotment hovels, a vast irregular agglomeration of ugly smoking accidents in which men lived as happy as frogs in a dustbin. Each thing jostled and damaged the other things about it; each ignored the other things about it, the smoke of the furnace defiled the pot-bank clay, the clatter of the railway deafened the in church, the public house thrust corruption at the school doors, the dismal homes squeezed miserably amidst worshippers the monstrosities of industrialism, with an effect of groping imbecility. Humanity choked amidst its products, and all its energy went in increasing its disorder, like a blind stricken thing that struggles and sinks in a morass.

H.G. Wells, **In the Days of the Comet**, 1906

Introduction

More than a hundred years ago, H.G. Wells, following in the tradition of Dickens, Jules Verne and other great 19th century novelists, railed against the pollution, the ugliness, the immorality, and the disorder of city life in the industrial society. In one scathing paragraph he raises vivid images of many of the disorders that have plagued cities for thousands of years and that persist to this day: pollution, noise, corruption, thoughtless development, and horrid environments for children. Today, other ills and other fears could be added to the list: climate change, over-use of fossil fuels, looming crises with respect to water supply, fears of lethal flu pandemics, terrorism, and even collapse of civilized life in more than one country. What is to be done?

What is to be done is what has always been done: recognize the problems, understand the causes of the problems, and try to do something to deal with the problems. The worst excesses of the Industrial Revolution that were so well depicted by Dickens have been eradicated by regulation of industry, better energy technology, and provision of social services to the poor. The "dismal homes squeezed miserably amidst the monstrosities of industrialization" have, at least in the developed countries, been succeeded by urban regions that have evolved into places more suitable for people. Humanity struggled mightily during the 20th century with its World Wars, political upheavals, and innumerable lesser wars and disasters, but for the most part, we have not yet sunk into the morass, and we seek to improve the world for our children and grandchildren.

Over the past two hundred years, investments in infrastructure have made astounding differences in the quality of life for most people in most areas of the world. First railways, then automobiles, buses, and airplanes brought mobility to unprecedented levels. With cheap transportation and warehousing, it is possible to ensure that food and other supplies are available throughout the world; droughts and natural disasters still cause hardship, but relief efforts can at least limit the amount of on-going loss of life and despair that once followed such calamities. Construction of reservoirs, aqueducts, and water treatment facilities eliminated the ravages of cholera and other diseases and allowed cities to grow without destroying the health of their citizens. The telegraph, then the telephone, and now the internet have made instantaneous communications a reality and a global perspective a necessity. Innovations in design and materials have reduced the costs of construction, allowed construction of skyscrapers, and made it possible to create great cities. Better regulations have helped to reduce air quality and water quality, and public and private initiatives have created hundreds of parks and ecological reserves.

We have made a great deal of progress. But much more remains to be done. People need to continue working to create a more sustainable world, and much of this effort must be allocated toward creating more sustainable infrastructure-based systems. This will be a slow process, because infrastructure systems last for decades and cannot be changed overnight. This will be an evolutionary process that incorporates and responds to new technologies, new management techniques, and major changes in society's perception of infrastructure needs and performance. This will be an important process, because we will all benefits as we move toward systems that can be more easily maintained, that are better suited toward society's needs, and that are less intrusive upon the environment.

Infrastructure evolves through a series of incremental steps, including specific projects and programs, incorporation of new technologies, development of better management strategies, use of new types of materials and energy sources, and new regulations concerning the use and design of infrastructure. It is important to take a long-term perspective in thinking about moving toward more sustainable infrastructure. While progress may be slow, progress is certainly possible. Understanding how infrastructure systems evolve can be helpful in looking at any proposed project. The historical context will always be important, and knowing about the different stages in infrastructure evolution can be helpful in determining whether a particular proposal is meaningful step in the right direction or merely an ill-fated attempt to keep an obsolete system functioning for a few more years.

Very few infrastructure projects are either completely new or completely independent. Most projects will be implemented using proven technologies and construction methods, and the completed project will fit into an existing network or an existing pattern of similar facilities serving much the same purpose. Project evaluation may often boil down to rather simple ideas: rents are high so this is a good time to build office buildings; roads are congested so let's build more roads; demand for electricity is growing so let's build more power plants; demand for water is growing, so let's build more reservoirs; the number of children is increasing so let's build more schools. In all of these cases, the needs are clear; the costs of building some more capacity are well-understood; and it is easy to figure out whether the investment is justified given the potential revenue from rents, tolls, or fees or the willingness of the public to pay taxes for schools and infrastructure. There may be long periods of time when society continues along a well-defined path, expanding infrastructure as needed to handle growth in population and rising demand for services.

However, these periods of stability will eventually be disrupted by fundamental changes in technology, institutions, political power, economic conditions, or societal norms. Technological innovation, which will continually be offering opportunities to improve the functioning of an existing system, will from time to time make it possible to introduce much better systems. In the early part of the 19th century, canals took freight from toll roads; a few decades later, railroads began to take freight from the canals; a hundred years later trucks operating over paved roads began to take freight from the railroads. And throughout this period, technological improvements for roads, canals, railroads, vehicles, and communications helped to reduce the costs of all kinds of freight transportation.

Table 1 indicates different stages that may be encountered in the evolution of transportation or other infrastructure-based systems. As with freight transportation, the evolution may be something that proceeds over hundreds of years, with different infrastructure systems emerging to support new technologies. Reaching a new equilibrium may take decades, and if technological innovation continues, an equilibrium may never be reached. Instead, the new systems will be growing side-by-side with the older systems that are in decline.

Table 1 Stages in the Evolution of Infrastructure-Based Systems

I	Technological Experimentation and Demonstration
II	Wide-Spread, Uncoordinated Implementation
III	Development of Systems
IV	Consolidation and Rationalization
V	Technological and Institutional Advancement
VI	Responding to Competition
VII	Mitigating Social and Environmental Impacts
VIII	Retrenching and Obsolescence

We will address each of these stages, keeping in mind that there is no pre-determined sequence or timetable for passing from one stage to another. The basic methods and concepts of project evaluation can be useful in any of these stages of development:

- Identifying needs and objectives and generating alternatives for meeting those needs.
- Specifying criteria for evaluating alternatives and conducting financial, economic, environmental and social analysis.

- Assessing the differences among alternatives using weighting schemes and an appropriate political process involving major stakeholders.
- Selecting the best strategy and refining it to increase efficiency and effectiveness and to mitigate negative environmental and social impacts.

Understanding the themes and issues that are likely to be encountered in each stage of development may be helpful in focusing the evaluation on the most relevant concerns and avoiding some of the most costly mistakes in evaluation. It is useful to understand how infrastructure-based systems have evolved over a period of decades in order to gain some insight in the evolutionary process. For example, several technological developments of the late 19th century made it feasible to build much taller buildings, which meant the economics of urban real estate were markedly and forever changed. The ability to make more intensive use of land led to dramatic increases in urban development, with a perhaps inevitable cycle of boom and bust. Railroads have been evolving for nearly 200 years, providing an even longer perspective on the evolution of an infrastructure-based system. Large portions of the rail system have already reached the final stages of obsolescence, and the railroads have already retrenched; operating over smaller networks using better technology, they are now serve fewer customers whose traffic is best suited to the low-cost service that railroads can provide.

Engineers, planners, politicians, corporations, and the public will faced major challenges in the 21st century in order to move toward more sustainable infrastructure. Many kinds of projects will be needed to meet these challenges, including rehabilitation of existing infrastructure in order to extend its useful life, replacement of certain elements of existing infrastructure in order to enhance performance, and construction of new infrastructure that embodies more sustainable technologies and designs.

Stage I Technological Experimentation and Demonstration

From time to time, someone comes up with a new technology that seems to offer a better means of satisfying some basic need of society. The first task is to figure out how to make the technology work, which may take years of experimentation and tinkering. Eventually there will be a demonstration that the new technology works, and there will be a few entrepreneurs or government agencies who back some initial implementations to determine whether or not the technology is financially feasible. Two hundred years ago, inventors figured out how to use a steam engine to pull a few cars along a railroad track at 10-20mph, which was a great improvement over a horse & wagon or a canal boat; in the 21st century, there are a few demonstrations of how to use magnetic levitation for a train to reach speeds close to that of airplanes. The railroad proved to be an extremely successful technology, and hundreds of thousands of miles of rail lines were constructed throughout the world within a hundred years of its introduction. It remains to be seen whether magnetic levitation proves to be a wide-spread alternative to air travel or remains an odd-ball tourist attraction for getting to and from the airport in Shanghai and perhaps a few other locations.

Relevant methodologies:

- Measuring System Performance: what kinds of performance improvements are most critical? What technologies are likely to provide such improvements in performance? How will any proposed technology affect cost, capacity, service quality, safety and other aspects of system performance?
- Probabilistic risk assessment: what are the risks associated with the new technology? How can those risks be minimized? Will the new technology be perceived as safe by potential users, abutters, and the general public?
- Performance-based technology assessment: will the anticipated improvement in performance be enough to attract users or supporters who will be willing and able to pay for the new system?

Potential pitfalls:

- Excessive investments in technologies that, even if successful, are very unlikely to attract much of a market.

- Introduction of a technology without adequate safeguards, leading to highly publicized failures that cause governments or the public to reject the technology.
- Introduction of a technology without adequate consideration of externalities, leading to government or public perceptions that the technology should be rejected because of its impacts on abutters, communities, or the environment.
- Failure to consider the potential impact of new technologies, thereby delaying the introduction – and deferring potentially large benefits – of new technologies.
- Government regulations that reject or hinder new technologies that would have broad benefits to society, but that are opposed by special interests.

Stage II Widespread, Uncoordinated Implementation

Once the technical and financial feasibility have been demonstrated, there will likely be a great many uncoordinated, fiercely competitive attempts to build up the infrastructure and related systems for the new technology. Once the automobile was shown to be feasible, dozens of manufacturers emerged, producing a great variety of styles and experimenting with steam and electrical systems for propulsion as well as with the internal combustion engine. The early automobiles had to use the existing roads, which were little better in 1900 than they had been in 1800 (and not as good as the roads that the Romans had built nearly 2000 years earlier).

Relevant methodologies:

- Financial Analysis: how will introduction of the new technologies be financed?
- Brainstorming, sensitivity analysis, and scenarios: what are the options for deployment? What are the factors that are most likely to affect success or failure?

Potential Pitfalls:

- Starting up too small, with insufficient coverage to attract enough users to support the service.
- Starting up too big, resulting in too much debt and too little revenue.
- Starting without adequate financial reserves, leaving the project vulnerable to a strong response from competitors or a downturn in the economy.
- Waiting too long to get started, which means that competitors capture the market.

Stage III Development of Systems

The initial, uncoordinated efforts will provide a great deal of information and insight concerning what is needed for reasonably efficient implementation of the new technology. Companies involved in network-based systems (such as electricity transmission, irrigation, transportation and telecommunications) will realize that there are economies of scale and density; they will try to expand, via construction or mergers, to obtain these economies. Cities will realize that some systems, such as water delivery, need to be coordinated to avoid costly duplication of infrastructure and to allow cost-effective services to customers. Companies and public agencies will decide how best to structure their systems, whether or not to integrate operations and maintenance of the systems, and how best to coordinate their activities with related activities.   During this stage of development, attention must be given to structuring and integrating infrastructure and operations so as to handle growth.

Relevant Methodologies**:**

- Determining the extent to which there are likely to be economies of scale, scope or density, i.e. understanding how costs and other aspects of performance vary with the structure of the system.
- Identifying and assessing strategic options for expansion.

<u>Potential Pitfalls</u>**:**

- Creation of unregulated monopolies that in fact achieve great reductions in average cost, but that are able to charge excessive prices for their services.
- Difficulties in consolidation caused by lack of interoperability, i.e. the failure of companies and agencies to develop compatible technologies that will facilitate coordination and cooperation.
- Competition that reduces prices to marginal costs that are below average costs, thereby limiting the ability to finance desirable increases in capacity or enhancements to facilities.

Stage IV Consolidation and Rationalization

It is frequently the case that the enthusiastic response to new technologies leads to overbuilding, the creation of infrastructure that has too little or too much capacity, and the inevitable problems in design and network structure that come from the initial uncoordinated investments. Even though the size and scope of the systems may be reasonable, there will be many opportunities for improving performance by consolidating portions of the system, by eliminating bottlenecks, and by abandoning pieces that are obsolete or underutilized.

<u>Relevant Methodologies</u>**:**

- Basic modeling of costs, service, competition and financial viability.
- Estimation of public benefits of consolidation and rationalization (in order to obtain public support and perhaps public funding for complex projects that will cause major disruptions during an extended period of construction).

<u>Potential Pitfalls</u>**:**

- Difficulties in abandoning underutilized portions of a network because of public pressures to maintain services viewed as necessary by customers and local governments.
- Difficulties in assembling tracts of land suitable for consolidated facilities.
- Difficulties in financing the investments in a competitive environment where prices are likely to fall quickly to new, lower marginal costs following completion of desirable projects.

Stage V Technological and Institutional Advancement

Managers, researchers, consultants, and regulatory agencies will continually be seeking new technologies, management strategies, and institutional arrangements that will improve the performance of the system. The goals during this stage are to reduce costs, enhance safety or improve service, taking advantage of better control technologies, better materials, or better management.   During this stage, system improvements come from looking inward so as to find opportunities for doing the job better. Technological advances may result in the use of new procedures or greatly improve the performance of what were thought to be obsolete procedures.

<u>Relevant Methodologies</u>**:**

- Basic modeling of costs, service, competition and financial viability.
- Performance-based technology scanning.
- Project and program audits.

Potential Pitfalls**:**

- Failure to provide for adequate maintenance and rehabilitation of the system.
- Failure to anticipate changes in competition, technology, or society; an over-confident management that may suddenly find that the capacity, cost, condition, or service quality of its infrastructure are woefully out of step with what is needed.

Example: New Technology Can Revive Old Methods – Wastewater Treatment in San Diego, California[1]

Recent technological advances have resulted in a major shift in the preferred methods for wastewater treatment. Metal salts were widely used in England in the 19th century to increase the level of coagulation and flocculation in municipal wastewater treatments. While the technique was effective, it greatly increased the amount of sludge that had to be disposed, adding substantially to the overall costs of treatment. As a result, by the 1930s, the preferred method of wastewater treatment changed to unaided gravitational settling followed by a biological process. New techniques, known as chemically enhanced primary treatments (CEPT), have recently improved the performance of primary wastewater treatment plants without generating nearly as much sludge. Since more of the pollutants are removed by CEPT, the demand upon the biological treatments is reduced. Research efforts at the Point Loma wastewater treatment plant in San Diego, California demonstrated the effectiveness of CEPT. Spurred by the need to meet new regulations regarding effluent, the operators came up with a CEPT method that was more efficient, produced minimal amounts of additional sludge, and increased the capacity of the system.

> *"Ultimately the system was so successful that Congress waived the usual requirement for secondary treatment, saving the city an estimated two billion dollars and allowing the construction of a tertiary water reclamation facility that now reuses 15% of the total wastewater flow instead of discharging it into the ocean."*[2]

CEPT is now seen as an excellent, low-cost option for treating wastewater, especially in the developing world, since this method makes it possible to achieve better performance from existing, over-burdened facilities.

Example: Replacing Old Infrastructure with More Effective Systems - Wastewater Treatment in Kaukauna, Wisconsin[3]

The Heart of the Valley Metropolitan Sewerage District of Kaukauna Wisconsin provides services to the city of Kaunauna and nearby towns. The district's original treatment plant was built in the 1930s, then converted into a regional treatment plant in the 1970s, and again upgraded and expanded in the 1990s. Two major factors made further enhancements necessary: population growth and stricter regulations regarding discharge. The district has a population of 42 thousand that was expected to grow to 68 thousand by 2029, which would cause peak demands to exceed the plant's capacity. Second, new state regulations required limiting ammonia nitrogen concentrations to 3.6 mg/L in summer and 10 mg/L in winter, while the existing facility discharged effluent with 20 mg/L. The crucial design problem was the lack of space, since the site had long since been hemmed in by a large mill on two sides and a canal and the Fox River on the other two sides. To handle the expected 100-year peak loads using conventional technology, it would be necessary to add substantial elements to the plant:

- Four primary clarifiers, each with a diameter of 115 feet and a capacity of 60 million gallons/day (mgd)
- Four final clarifiers, each with a diameter of 90 feet and a capacity of 25.4 mgd
- A nitrifying aeration basin area of an acre (200 ft by 200 feet)

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[1] Michael R. Bourke, Donald R.F. Harleman, Heidi Li, Susan E. Murcott, Gautam Narasimhan and Irene W. Yu, *Innovative Wastewater Treatment in the Developing World,* **Civil Engineering Practice**, Spring/Summer 2002, pp. 25-34

[2] Bourke et al., op. cit., p. 27

[3] Thomas E. Vik, Mark Surwillo, *Small Footprint, Big Promise*, **Civil Engineering**, February 2008, pp. 66-85.

Since the site was too small to accommodate these new facilities, it was impossible to consider using conventional technology at that site. The possibility of acquiring a new site was considered, but deemed to be too expensive. Instead, the District decided to use more efficient treatment processes, some of which had been used in Europe, but not in the U.S. To implement the new systems, the District was able to convert portions of the old facility to new uses, to replace some of the old plant with portions of the new system, and to convert some open space and a parking lot to other portions of the new system. The end result was a treatment plant that required a much smaller footprint, provided much higher capacity, and removed much more of the pollutants. Table 2 shows how the primary treatment technologies that were implemented as part of this project used a tenth of the space while removing more of three key pollutants: carbonaceous biochemical oxygen demand (CBOD), total suspended solids (TSS) and phosphorous.

Table 2 Comparison of Conventional Primary Treatment Technologies with Those Implemented in Kaunaua

	Area of Facilities	**Removal of CBOD**	**Removal of TSS**	**Removal of Phosphorous**
Conventional	40,000 sq. ft.	30%	50%	0%
Kaunaua	3,850 sq. ft.	50-60%	70-80%	75-85%

This example provides two major lessons. First, new technologies may make it possible to use existing sites far more effectively by reducing the footprint required for key facilities. Second, new technologies may be more effective, thereby resulting in a better level of service for the infrastructure.

Stage VI Responding to Competition

No system is immune to competition, and competitive threats are likely to increase as the system ages. Competition will reduce demand for a system, and over time competition could eliminate the need for a system. Several kinds of threats are possible:

- **Competition from similar systems**: competition is based upon the ability of the competitors to use similar technologies to provide services to customers.
- **Competition from systems based upon different technologies to provide the same service**: in this type of competition, the competitors use completely different technologies to serve the same types of needs.
- **Competition from systems based upon different technologies that eliminate the need for the service**: in this type of competition, some kind of technological innovation provides a new way of doing business that has the potential for reducing the demand for existing services.

Relevant Methodologies**:**

- Basic modeling of costs, service, competition and financial viability.
- Performance-Based Technology scanning.
- Brainstorming and scenarios.

Potential Pitfalls**:**

- Failure to consider how current conditions might change.
- Overconfidence based upon past glory or past profitability.
- Regulations relevant to old technologies that limit the introduction of new technologies that may require less frequent inspection, support higher loads, or allow different methods of operation

Examples: Competition Faced by the Airline Industry

Competition from Similar Systems: Low-Cost Airlines Competing with Legacy Airlines

During the late 20th century, new airlines decided to serve selected markets from smaller airports using low-cost crews and new, efficient planes. Some of these airlines, notably Southwest Airlines in the U.S. and Ryan Air in Europe, were extremely successful with this strategy and diverted substantial numbers of people from the older airlines. The success of these airlines helped provide an impetus to upgrade facilities and expand capacity at airports in many smaller cities. Airports in Manchester, New Hampshire and Providence, Rhode Island, which are about 50 miles from Logan Airport in Boston, began to compete with Logan for the same air travelers.

Competition from Systems Using Different Technologies to Provide the Same Service: High-Speed Rail Competing with Airlines

High-speed railroads can compete effectively with airlines for trips of 200 to 500 miles. Which mode captures the largest share of the market will depend in part upon technological capabilities and in part upon public policy toward investing in transportation. In many airports, a large percentage of travelers are taking these medium-distance trips, so diverting travelers to trains can reduce the need for investment in airport capacity.

Competition from Systems Using Technologies that Eliminate the Need for the service: Telecommunications Competing with Airline Travel

Video conferencing facilities, cheap telecommunications, and the internet allow virtual conferences that reduce the need for business travel; email allows the exchange of information without requiring the use of the post office; catalog or internet shopping allows people to purchase items without visiting stores. These changes reduce the demand for business travel, reduce the use of aircraft for mail, and increase the use of air freight to support delivery of all those items ordered on-line.

Stage VII Mitigating Social and Environmental Impacts

Social and environment impacts are likely to become more important over the life of any infrastructure-based system for two primary reasons. When a system is first developed, the societal needs may be so clear that any obvious negative impacts of the new system are easily accommodated. However, society eventually demands that something be done about these problems. For example, the benefits of railroads and automobiles in enhancing mobility and opportunity far outweighed the fact that both modes were originally very noisy, dirty and risky.

After a system has been functioning, it may become apparent that its social or environmental impacts are unacceptable. As automobile accidents began to account for tens of thousands of fatalities annually, highway safety became a major issue in both vehicle design and highway design. When the public realized that drunk drivers caused a high proportion of the fatalities, they forced government agencies to impose stricter penalties and greater enforcement of laws intended to reduce driving while drunk.

Implementation of new technologies often creates problems that were not anticipated and that were only identified after many years or decades of experience. For example, automobile exhaust was not a major public concern until well after there were enough automobiles to cause a noticeable degradation in air quality. The initial concerns about automobile emissions were related to air pollution and its effects on visibility, deterioration of buildings, and above all human health. By 1970, it was clear that automobile exhaust contributed heavily to smog and that air pollution was a serious health problem. About that time, governments began to impose regulations on emissions and on fuel consumption, with the result that air quality improved despite increases in automobiles and trucks. The efforts to reduce emissions focused on pollutants, including carbon monoxide, hydrocarbons, and nitrogen oxides. In the United States, emission standards for new vehicles were first imposed in 1968 and strengthened with the passage of the Clean Air Act in 1970. Within twenty years, the average emissions of carbon monoxide and hydrocarbons from new cars were only 4% of what they had been in 1970, while emissions of nitrogen oxides were only a quarter of what they had been. These dramatic improvements were enabled by a new technology, the catalytic converter, which effectively prevented the release of most of these pollutants.

Although the air quality in major cities improved because of regulation of emissions, a new, more difficult problem emerged, namely the threat of global warming and climate change. As the 20th century came to an end, scientific evidence increasingly pointed to an accelerating world-wide rise in average temperatures and a link between global warming and the emission of greenhouse gases. These gases not only included carbon monoxide, hydrocarbons and nitrogen oxides, they also included carbon dioxide, which is much more difficult to control and which is not normally considered to be a pollutant. By the early 20th century, the threat of global warming was clearly linked to the increasing levels of carbon dioxide in the atmosphere. Today, there are serious efforts to reduce consumption of all fossil fuels, and, in particular, to develop alternative fuels for and to increase the fuel efficiency of automobiles and trucks. In the U.S., federal legislation required the use of ethanol as an additive to gasoline. Ethanol can be produced from corn, sugar cane or other biological sources, so the use of ethanol can reduce the use of fossil fuels. This legislation led to the construction of numerous facilities for producing ethanol along with substantial investment in rail lines that would serve the new ethanol plants. The requirement for using ethanol in gasoline created such an increase in the demand for corn that the price of corn for food increased around the world - another problem that society must deal with.

Other problems that will influence the evolution of infrastructure in the 21st century include:

- Awareness that activities in one area are threatening the environment in other areas.
- Concerns for energy cost may require new materials and new designs for buildings and transportation systems.
- Societal norms may change, making environmental quality and sustainability much more important factors in evaluation factors.
- Societies may decide to devote more resources toward protection from natural disasters such as earthquakes, tsunamis, and hurricanes.

The following examples illustrate some of the problems that have emerged and some of the steps that have been taken to deal with them.

<u>Activities in one area threaten the environment in other areas:</u> widespread use of irrigation and fertilizers were part of highly successful efforts to improve the yield of farms in the Midwestern U.S. Vast networks of irrigation canals and drainage systems were used to make it possible to farm areas that otherwise would have been too dry or too wet. Moreover, in order to maximize production, lands very close to waterways and wetlands were cultivated. As a result of these agricultural practices, excess fertilizers are washed into the rivers that feed into the Mississippi River and eventually flow into the Gulf of Mexico, with devastating consequences.

<u>Concerns for energy cost influence design of buildings</u>: as energy costs and public concerns with global warming rise, companies are beginning to be interested in reducing the energy required in large buildings. For example, the Pearl River Tower in Guangzhou, China was designed to be the most energy efficient of the world's tallest skyscrapers. Although the original goal of being energy neutral proved to be too expensive, the building is expected to consume less than half of the energy of a similar building that was built to a traditional design.[4]

An independent, third-party rating system has been developed that certifies sustainable building practices that is used by many companies interested in being leaders in sustainable construction (see text box). LEED certification is available for different kinds of construction, including office building, apartment buildings, schools and homes. A complex set of criteria has been established for each type of building, and points are awarded for such things as energy efficiency, water conservation, and landscaping. Detailed information is available from the website of the U.S. Green Building Council.

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[4] Roger E. Frechette III and Russell Gilchrist, "Seeking Zero Energy", **Civil Engineering**, January 2009, pp. 38-48.

LEED Certification and the Design of "Green Buildings"

"The Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ encourages and accelerates global adoption of sustainable green building and development practices through the creation and implementation of universally understood and accepted tools and performance criteria.

"LEED is a third-party certification program and the nationally accepted benchmark for the design, construction and operation of high performance green buildings. LEED gives building owners and operators the tools they need to have an immediate and measurable impact on their buildings' performance. LEED promotes a whole-building approach to sustainability by recognizing performance in five key areas of human and environmental health: sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality."

U.S. Green Building Council, www.USGBC.org

Reducing the risks of earthquakes: it is possible to build structures that are more likely to withstand earthquakes, and it is possible to design systems that are more likely to continue operations even if an earthquake destroys some of its components. New buildings and other structures in earthquake zones are today designed to withstand earthquakes. In many locations, structures are strengthened so that they will be more likely to withstand the lateral and vertical movements that could be causes by an earthquake. In Japan, for example, where earthquakes are a very common experience, JR East and other railroads retrofitted many of their bridges to reduce the risk that a high-speed train would derail or overturn in the event of an earthquake. In northern California, it was decided to retrofit the Claremont Tunnel, which was constructed in 1929 to transport water to Oakland and other cities. If a portion of this tunnel were destroyed, then a half million people would be without water. To avert such a disaster, the East Bay Municipal Utility District spent $66 million to construct a by-pass tunnel through the fault zone. The by-pass tunnel was designed to accommodate a lateral movement of up to 8.5 feet (2.6m).[5]

Societal norms change – the need for instant communication: Over time, as societies become more affluent, they tend to be less tolerant of risk, more interested in style and aesthetics, and more conscious of the factors that affect their personal well-being. As a result, systems that were acceptable when built may no longer be acceptable twenty or fifty years later.

Changes in societal expectations are perhaps most notable in the area of telecommunications. In ancient history, the Persians, Chinese, and Romans built highways that were intended in part for armies to move quickly throughout their empires. The same roads were also used to provide communications between the capital cities and the other cities and states that were part of the empire. In the mid-19th century, the telegraph allowed instantaneous communications – but at a cost that only governments and corporations could afford on a routine basis. The telephone provided direct communication for the masses, but the cost for long distance calls was so high as to make each such call a family event just 50 years ago. Cell phones freed users from their land lines, and allowed people to make calls from almost anywhere to almost anywhere. Today, e-mail, texting, the world-wide web, and twitter today allow people to be in almost continuous contact.

Societal norms change – airline terminals resemble shopping malls. Travelers are no longer willing to go to the airport, check-in, and sit patiently waiting to board their plane, and they can no longer show up just before flight time, because of the need to pass through security. Thus, it is no longer enough to provide a few seats near the departure gates. Moreover, it is clear that people are willing to spend quite a lot of money when they are forced to spend a half hour or more in a confined area. Airports today must have restaurants, shopping opportunities, first-class lounges, internet

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[5] Sarah Holtz Wilson, David F. Tsztoo, Carl R. Handford, and Kenneth Rossi, "Safeguarding a Lifeline," **Civil Engineering**, May 2008, pp. 58-65

connections, and attractive design; these features not only improve the comfort and quality of the traveling experience, they provide income to help pay for the expansive and expensive terminals. For similar reasons, colleges today not only require adequate housing for students, they also must provide excellent sports facilities and dining options and wireless internet connections in every classroom and in every dormitory room. The quality of the living experience may be as important as the quality of the education for students deciding where to apply.

Example: Evolution of London and the Thames Embankment

The Victoria Embankment was constructed in the 1860s for multiple purposes, including creation of open space along the river. It also helped to channel the river and provided space for a new sewer system and an underground railway.[6] Upgrading infrastructure, coordinating major investments affecting different kinds of infrastructure, invigorating downtown areas, creating more walkways to encourage pedestrians, and highlighting a city's architecture are all part of what is needed to create more sustainable cities.

St. Paul's, a magnificent structure that was constructed following the Great London Fire of 1666, was barely visible from the tourist boats plying the Thames. In 2000, a new pedestrian bridge linked the historical center of the City with the rapidly re-developing South Side. Pedestrians walking across the river are now treated to an unhurried view of this architectural gem (Figure 1). The bridge also connects well designed walkways along the south side of the river with the 19th century linear park along the north side.

Figure 1 St. Paul's Cathedral and Millenium Bridge, London

[6] For the history of London's sewers and the construction of the embankment, see Stephen Halliday, **The Great Stink of London: Sir Joseph Bazalgette and the Cleansing of the Victorian Metropolis**, Sutton Publishing, Phoenix Mill, England, 1999.

Example: Building New, More Sustainable Infrastructure: One Bryant Park[7]

Bank of American, working with the Durst Organization, designed their 55-story headquarters so as to achieve the highest level of LEED certification, thereby demonstrating their commitment to sustainable development. In order to become one of the first skyscrapers to achieve platinum certification, the new Manhattan skyscraper had to incorporate sustainable features that distinguish it from conventional office towers:

- Energy requirements:
  - The building has a 4.6 MW natural gas-fired power plant; excess heat is used to heat hot water for heating the building in the winter and cooling it in the summer via an absorption chiller.
  - A thermal storage plant is located in the basement that produces ice at night, when energy demand is low and helps with air-conditioning during the day. This reduces the building's peak energy requirements, thereby lessening the demand for electricity from the most polluting and least efficient power plants serving the city (since these plants are only used during peak periods).

- Water requirements are half that of a conventional building:
  - Rail water is collected and used as grey water to flush toilets and supply the cooling system
  - Waterless urinals are used in all men's restrooms, saving three million gallons per year

- Interior design is healthier than a conventional building:
  - The interior incorporated many recycled materials and avoided materials with volatile organic compounds.
  - The heating and ventilation systems filter out 95% of the airborne particulates, compared to 35% for a conventional building; the air discharged from the building is cleaner than when it entered.
  - The glass-shrouded building lets in natural light

- Use of recycled materials in the structure
  - The 25,000 tons of structural steel had at least 75% recycled content.
  - 45% of the cement used in the building was granulated blast furnace slag (GBFS), a waste product of steel smelting that produces a stronger, denser, and more durable concrete. Use of GBFS was estimated to reduce material waste and new cement by 17,000 tons each, while also reducing the emission of carbon dioxide by nearly 16,000 tons.
  - The construction process resulted in less debris and less need for recycling.

- Integration within the city:
  - An underground pedestrian walkway will eventually connect subway stations on the north and south sides of the site and a mid-block subway entrance will eventually be added.
  - The tower's entrances are sited to enhance access to Bryant Park.
  - The project helped in the reconstruction of Henry Miller's Theatre, a playhouse located on a corner of the site.

The $1.3-billion building includes 2.2 million square feet of office space, most of which was initially occupied by Bank of America beginning in 2008. In addition to its sustainability, the iconic building is noted for its beauty, as it "features crisp folds that appear to be sculpted and precise vertical lines animated by the movement of the sun, the clouds, and the moon."

It is clear from this example that it is possible to build high-rise buildings that are much more sustainable in terms of their materials requirements, their energy and water needs, the quality of the indoor environment, and their integration

[7] Andrew Mueller-Lust, *Crystal Clear*, **Civil Engineering**, December 2008, pp. 38-71. The tower is owned by One Bryant Park, LLP; it was developed by the Durst Organization; and Band of America is the largest tenant. The architect of record was Adamson Associates Consulting Engineers, P.C.

with the nearby urban environment. Whether the innovations used in One Bryant Park will be cost-effective in other applications is something that designers will have to determine for other locations and for other building projects.

Stage VIII Retrenching and Obsolescence

Competition and changes in societal needs will cause some systems to shrink and perhaps disappear. If well-managed, a system can decline slowly, over a matter of decades, by continually eliminating unnecessary or unprofitable components and cutting back to profitable core operations. If poorly managed, a system may simply hold on for too long, then suddenly collapse. Today, there is an on-going drama involving telecommunications. Are land-lines obsolete? Will everyone go wireless? Will people communicate only via the internet? What will happen to all of those telephone poles?

As with the previous stages, many of the standard methodologies of project evaluation will be useful in deciding whether or not a system or technology is obsolescing and, if so, figuring out how to age gracefully. Short-sighted management may fail to foresee problems until it is too late to do anything; bull-headed managers may decide to invest vast sums to rehabilitate a system that is actually no longer competitive. Some of the largest expenditures on rail passenger stations were made in the 1930s, just at the time when air travel and automobiles were about to put most rail passenger services out of business. It is far better to have a realistic outlook on competition than to blindly go ahead with major investments aimed at providing marginal improvements to a system that is more than marginally non-competitive.

21st Century Challenges: Sustainable Infrastructure

Technological changes can, over time, dramatically affect the way that infrastructure is designed, how it is used, and how it impacts society. For skyscrapers, railroads, and other types of infrastructure, technology has allowed great reductions in cost, but regulation has been required to curb private sector excesses related to pricing, aesthetics, over-building, or safety. Skyscrapers and railroads today are more energy efficient, more attuned to user needs, and more sustainable that they were 50 or 100 years ago. Presumably both types of infrastructure will continue to evolve in response to social, economic, financial, and environmental pressures.

Today, the need to consider sustainability is much more evident than it was in the 19th century at the height of the industrial revolution. The impetus to consider sustainability comes from various sources:

- Over-dependence upon fossil fuels.
- Global warming and related aspects of climate change: more severe weather patterns, rising sea-levels, threats to ecosystems.
- Societal concerns with equity and social justice: the vast difference in quality of life in different countries and the vast inequality in incomes among the richest and poorest within each country.
- Instability in many societies related to disintegrating economies, internal conflicts, and lack of opportunity.
- Congestion and pollution within the largest cities: are there limits to growth? What can be done to improve quality of life in mega-cities, especially in developing countries?
- Cracks in the automobile culture: recognition of the disproportionate amount of resources devoted to automobiles and highways, the enormous loss of life on highways, the dependence upon fossil fuels, the contribution to green-house gases, and the waste of time and resources caused by urban congestion.
- Environmental degradation, including an accelerated rate of extinction of species, loss of habitat, the long-term threat of toxic chemicals to the water supply, and erosion.

These factors will influence how infrastructure performance is measured, how goals are established, how problems are defined and how project and programs are evaluated in the 21st century. However, the same multi-objective framework for evaluating infrastructure projects will remain useful, even if the relative importance of cost, environmental quality, sustainability change dramatically. Financial analysis will remain important, because an essential aspect of sustainable infrastructure will always be the ability to raise the cash to pay for construction, maintenance, and operation, and the ability to raise cash ultimately will reflect what is going on in the financial markets. The ability to deal with uncertainty and risks, the ability of the public and private sectors to work together, and the ability to manage projects and program will all continue to be essential aspects of the development and evolution of infrastructure systems.

Enhancing the sustainability of infrastructure will be a continuing challenge for planners, engineers, and politicians in the 21st century. Urban problems related to pollution, congestion, disease, water supply, wastes, and natural disasters will grow, especially in mega-cities in developing countries, but also in all large or rapidly growing metropolitan areas. Battles over water supply will intensify, and the needs for waste water treatment will increase. Renewable energy sources will need to be developed to lessen dependence upon fossil fuels, and safer, more efficient, more secure systems will be needed for greatly expanding the role for nuclear energy. It will be necessary to transform transportation and land use patterns that were developed over decades when oil was cheap, highways were easy to build, and cities were forsaken. Massive efforts will be needed to create or protect the world's green infrastructure and to reverse some of mankind's worst encroachments on harbors, waterways, wetlands, and threatened ecosystems.

Responses to these challenges will include efforts in many different areas:

- Managing the demands on infrastructure.
- Maintaining and rehabilitating existing infrastructure.
- Managing infrastructure more effectively.
- Using infrastructure more effectively.
- Mitigating the negative social and environmental impacts of existing infrastructure.
- Building new, more sustainable infrastructure.
- Retiring old, unsustainable infrastructure.

In any of these areas, success will depend upon the same factors that have been emphasized throughout this collection of essays and case studies:

- Clear identification of the problems.
- Development of objectives and measurable criteria.
- Generating possible alternatives for dealing with the problems.
- Analyzing alternatives with respect to financial, economic, social an environmental impacts.
- Selecting and refining the most promising projects and programs.
- Implementing projects and programs efficiently and effectively.
- Monitoring performance and taken actions as necessary to achieve the objectives of the project.

The evolution of infrastructure depends to some extent on leadership, innovation, technologies, and regulation. Efforts to transform infrastructure do not happen overnight, and it may take time for society to recognize either the need for changes or the need to regulate development. Once the technology for high rise construction was available, real estate economics quickly drove buildings skyward in Chicago and New York; however, only after several decades of unfettered development, were city authorities able to institute zoning regulations to preserve light and air quality by requiring setbacks as the towers rose from street level. The rail industry struggled for nearly a century to transform itself from its role as the dominant transport mode of the late19th century to a well-managed niche player with potential for growth at the beginning of the 21st.

Summary

Most infrastructure projects are completed as an extension to, as an upgrade of, or as a competitor to an existing system. Infrastructure projects therefore are almost always conceived and evaluated in the context of existing systems. At times, perhaps for very long periods of time, there will be very clear projects that can and should be implemented with little or no controversy and with little or no need for extensive analysis. Projects that improve the performance of a successful system or projects that replicate systems in new locations may not require a great deal of specialized evaluation, because the costs and benefits associated with such projects are well understood. However, over time, changes in technology, institutions, political power, economic conditions or societal norms will lead to new ideas for projects, new estimates of the potential costs and benefits of projects, and new criteria for evaluating projects.

It is useful to consider the stages in the evolution of an infrastructure-based project, for the opportunities and problems are different in each stage. Table 3 lists some of the questions that are to be encountered in each of the seven stages of evolution that have been discussed in this essay. These stages are not necessarily sequential, and different parts of a large system may well be at different stages of development. For example, the infrastructure required to support cell phones and other wireless communications is still in the early stages of evolution, while the infrastructure used to support traditional land-line telephones is in the latter stages of evolution – even though the same companies may be involved in both types of communication.

Over time, society's needs and resources change, and as they change, the roles for and perceptions of infrastructure will also change. In the 19th and 20th centuries, new technologies and mammoth infrastructure projects enhanced mobility, helped make agriculture more productive, allowed more intensive urban development, provided heat and light, and shrank the world, together creating unprecedented prosperity and a global economy, While many of the consequences of these technologies and project have been highly beneficial, there have also been negative consequences, including pollution, over-dependence upon non-renewable energy sources, congestion, excessive use of water, inequalities in development, and degradation of the environment. In the 21st century, much of the interest in infrastructure will be aimed at resolving these problems and extending the benefits of modern technology to all regions of the world. Many projects and programs will need to be initiated in order to move the U.S. and the world toward more sustainable infrastructure.

Efforts to create more sustainable infrastructure will likewise takes decades of steady progress. While examples abound to illustrate how different systems are evolving, it is unclear which approaches will be most successful and which will ultimately be found to be too costly, too inefficient, or ineffective.

Table 3 Stages in the Evolution of Infrastructure-Based Systems

I	Technological Experimentation and Demonstration • Will the technology work? • Will investors support projects? • Will there be a market for the new technology? • Will public agencies approve the new technology?
II	Wide-Spread, Uncoordinated Implementation • What will be needed to implement the new technology? • Who can build the fastest? • Whose approach will be the best? • What is needed to obtain public approval for new or expanded systems?
III	Development of Systems • How can we achieve economies of scale and density? • What organizational structure is best? • How much coordination is required among government agencies and developers or private companies? • What is the best way to handle growth? • How can we avoid overbuilding?
IV	Consolidation and Rationalization • How can we rationalize the system so as to become more efficient and more effective in providing services? • What is the optimal structure of our system?
V	Technological and Institutional Advancement • What is the source of competition: similar systems, different technologies that provide the same service, or systems that eliminate the need for the existing service? • What is the role for new technology? • How can the system be managed and regulated more effectively?
VI	Responding to Competition • What is the best role for the system? • Can the system survive competition?
VII	Mitigating Social and Environmental Impacts • How can the system respond to changes in societal views of the role of the system and the nature of its impacts on society and the environment? • How can negative social and environmental externalities be mitigated?
VIII	Retrenching and Obsolescence • When is it necessary to downsize? • What is the best approach to downsizing? • How can the system be re-used, recycled, or dismantled?

Case Study
The Franconia Notch Parkway

Sometimes the best solution requires a compromise that results in a project that is more limited than what proponents wanted to build, but enables the project to be accepted by the general public. When Interstate 93 was first planned for central New Hampshire, the Federal Highway Department insisted upon using standard design criteria, namely a four-lane divided highway with few exits. However, the proposed project would have obliterated the central portion of Franconia Notch, the flagship of New Hampshire's state park system, causing great consternation with the public and local conservation organizations. After much discussion, FHWA backed down, and the damage to the park was avoided by upgrading the existing two-lane highway and limiting the width of the right-of-way within the most environmentally sensitive areas of Franconia Notch.

Environmental issues can be easy to understand or very complex, and they can generate dramatic controversy. Franconia Notch, illustrated in Figures 1and 2, is one of the most beautiful spots in the White Mountains of New Hampshire. Most of the area visible in the photos is part of Franconia Notch State Park, which includes a swimming beach, an aerial tramway to the summit of Cannon Mountain, ski trails, and hiking trails. The Notch is also the historical route for traveling between southern New Hampshire and northern Vermont – and therefore the natural route for an interstate highway. The route was indeed part of the original plan for Route I93, but controversies arose concerning how to fit the standard four-lane divided interstate highway into what little room is available between the Lafayette range on the east (the left side of the pictures) and the Kinsman range to the west. One plan developed by highway planners was to blast a tunnel through Mt. Skookumchuck (the rocky outcrop at the head of the notch that is clearly visible in the middle of the picture) so that the four-lane divided highway could plow straight through the notch. This plan would have obliterated two small ponds, cut off much of Echo Lake (the lovely lake visible in the photo that is used extensively for swimming and fishing) and taken up nearly all of the flat land available in the upper portions of this narrow valley.

Local opposition prevented this option and all other attempts to build a highway to interstate specifications through the notch. The public's interest in the project was represented by the Appalachian Mountain Club, whose members maintained and hiked the many trails in these mountains, and the Society for Preservation of New Hampshire Forests, which had purchased this land more than 80 years ago and contributed it to New Hampshire for use as a state park. These two organizations worked with the NH Department of Transportation to find a less intrusive solution that preserved more of the park yet allowed better transportation. Instead of the typical interstate, the existing road was enhanced, but not widened, and a better link was thereby made between the sections of I93 that were completed north and south of Franconia Notch. Since the new road had only a 45 mph speed limit and narrowed to a single lane in each direction for several miles, it was clearly not up to interstate standards. Moreover, it had frequent exits for access to the Notch's attractions, including the viewing spot for the much loved but recently collapsed Old Man of the Mountain – a striking rock formation that is now visible only in photos and on the obverse of the New Hampshire quarter (the only US coin with two heads). For many years, the Federal Highway Administration refused to classify the road as an interstate, and it was officially known as the Franconia Notch Parkway. FHWA eventually relented and, early in the 21st century, the Franconia Notch Parkway officially became part of the interstate system, despite its obvious deficiencies. Today, the stretch of road visible in these photographs is the only two-lane portion of the entire Interstate Highway System. The compact between NH DOT and the two conservation groups remains in place. These three parties worked together in 2009 to develop plans for resurfacing the roadway, repairing drainage, replacing guardrails, improving the landscaping, and keeping the small footprint of the highway unchanged. The compromise decision to allow a slimmed-down interstate highway to be constructed through this scenic region was an early example of what is now referred to as **context sensitive design**. Considerable environmental disruption can be avoided by tailoring infrastructure to the local geography and environmental conditions instead of insisting upon the use of standard procedures.

Figure 1 Franconia Notch, with Mount Lafayette in the distance, Skookumchuck in the left center, and Echo Lake in the lower right.

A road built to interstate standards would have destroyed much of the scenic sites within Franconia Notch State Park. However, a two-lane road provides sufficient capacity for this rural portion of the interstate, and it has little impact on the state park. This road, completed in 1983, is an early example of what is now called “context sensitive design.”

Figure 2 Franconia Notch Parkway at the edge of Echo Lake

This narrow, but highly scenic two-lane road is now part of Interstate 93. This picture, which was taken on the same day as the previous picture, shows how little space is taken up by the highway as it skirts the shoreline of a lake and a valley that are famous for their recreational opportunities: swimming, fishing, hiking, biking and snowmobiling.

Case Study
Weighting Schemes for Evaluating Options for Increasing Bus Capacity

Weighting schemes cannot be accepted as an objective way to compare alternatives. This hypothetical case study illustrates how each group interested in expanding the capacity of a transit system can devise a weighting scheme that will rate their preferred option as the best option.

Table 1 shows how four hypothetical options for improving the performance of a bus system might affect various aspects of performance. The system currently has 300 buses, some of which are old and inefficient. Strategies for improving performance of the system include buying new buses, creating a busway within the downtown area in order to allow buses to avoid congestion, and developing a control system that would improve performance by enabling dispatchers to monitor the location of and the number of people on every bus. Buying new buses would have two effects: increasing the number of scheduled operations, thereby improving service and allowing the system to handle more passengers. With new buses, the oldest 25 buses could be retired, and the average fuel efficiency of the fleet would increase while the average emissions would decline. If new buses were purchased, it would be possible to reduce emissions by ordering cleaner, but more expensive, hybrid buses. If more buses were acquired, the agency planned to create a new servicing facility for the buses on land that the agency owns; several businesses that currently rent space from the transit agency would have to be moved from this site. If the city were to build a busway and create some bus-only lanes, it would be able to provide much faster service and run additional trips without increasing the size of the fleet. Finally, if the city were to install a state-of-the-art control system, it would be able to get some improvement in travel times, ridership, and emissions for a much lower cost than any of the other options.

Table 1 Predicted Cost and Performance for Expanding Capacity of a Bus System

	Cost	Improvement in Travel Times	Increase in Ridership	Reduction in Emissions per Bus-Mile	Families & Businesses to Relocate
Buy 100 new buses	$50 million	5%	20%	10%	10
Buy 75 new hybrid buses	$60 million	4%	15%	40%	10
Create a busway	$200 million	20%	30%	8%	30
Install a control system	$20 million	10%	5%	5%	0

None of the proposals dominates all of the others, and three of the proposals look best in terms of at least one of the criteria. Buying hybrids provides the greatest reduction in emissions, while creating a busway would lead to the greatest increase in ridership and installing a control system would be the least costly. Table 2 shows how the proposals rank by each criteria. These are call **ordinal rankings**: first, second, third, or fourth. The total column simply adds the five numbers, so that it is a measure that weights each of the criteria equally. If the best option is the one with the lowest total, then the best option would be to buy 100 new buses.

Table 2 Summing Ordinal Rankings for Each Criterion to Obtain an Overall Ranking

	Cost	Improvement in Travel Times	Increase in Ridership	Reduction in Emissions per Bus-Mile	Families & Businesses to Relocate	Total
Buy 100 new buses	2	3	2	2	2	11
Buy 75 new hybrid buses	3	4	3	1	2	13
Create a busway	4	1	1	3	3	12
Install a control system	1	2	4	4	1	13

It is unlikely that any group of planners or financial managers or government officials or public interest groups would simply accept this result. Those who really want the busway, such as the Transit Agency's Strategic Planning Group, might argue that capacity and ridership are the main goals. They might propose weighting travel time and ridership three times as heavily as the other criteria. As shown in Table 3, creating a busway now looks best.

Table 3 Weighting Scheme Proposed by the Transit Strategic Planning Group

	Cost	Improvement in Travel Times	Increase in Ridership	Reduction in Emissions per Bus-Mile	Families & Businesses to Relocate	Total
Weight:	1	3	3	1	1	
Buy 100 new buses	2	3x3	2x3	2	2	21
Buy 75 new hybrid buses	3	4x3	3x3	1	2	27
Create a busway	4	1x3	1x3	3	3	16
Install a control system	1	2x3	4x3	4	1	24

The operators and the bus passengers association, who really want some immediate relief from overcrowded, unreliable buses, support the concept of bus lanes and busways, but what they most want is new buses. They point out that the busway will take three years to complete, and they also wonder why it should be possible to get hundreds of millions for capital improvements when budgets have been so tight that it has been necessary to freeze salaries for managers and raise fares. The General Manager of Bus Operations argues for high weighting only for cost and ridership, which he views as the key factors, and he claims that relocating small businesses who rented space is not an issue, as those businesses knew very well that their building would eventually be needed for the bus servicing facility. He therefore argued for a revised set of weights as shown in Table 4.

Table 4 Weighting Scheme Proposed by the General Manager of Bus Operations

	Cost	Improvement in Travel Times	Increase in Ridership	Reduction in Emissions per Bus-Mile	Families & Businesses to Relocate	Total
Weight:	2	1	2	1	0	
Buy 100 new buses	2x2	3	2x2	2	2x0	13
Buy 75 new hybrid buses	3x2	4	3x2	1	2x0	17
Create a busway	4x2	1	1x2	3	3x0	14
Install a control system	1x2	2	4x2	4	1x0	16

The local environmental groups, who are a major political force in the city, push very hard that investing in clean buses would have a dramatic impact on the air quality of the city. Furthermore, they argue that the city should set a high standard when it comes to cleaning up the environment. They say that the city should buy however many hybrid buses it can afford to establish a long-term commitment to improving the environment. They also dislike the ranking scheme as structured in all of the above charts, as some of the differences among options are small, while others are very high. They recommend normalizing each of the measures by dividing by the measure for the best option for each criteria where a lower number is better and using the inverse when a higher number is better. Hence, the hybrid bus cost of $60 million would be divided by $20 million, the cost of the lowest cost option, to get a value of 3 for the cost criteria. The hybrid bus value of 40% reduction in emissions is in fact the best, so dividing 40% by 40% would give a value of 1 for the hybrid buses reduction in emissions. They also agree with the notion that there would be no real relocations caused by the creation of the bus servicing facility, so they simply dropped that criteria. Finally, they interpreted the use of weights to be merely an exercise in promoting special interests; once the relevant criteria have been identified, they weight everything equally. Their proposed ranking is shown in Table 5.

Table 5 Weighting Scheme Proposed by Environmental Groups

	Cost	Improvement in Travel Times	Increase in Ridership	Reduction in Emissions per Bus-Mile	Total
Weight:	2	1	2	1	
Buy 100 new buses	50/20 = 2.5	20%/5% = 4	30%/20% = 1.5	40%/10% = 4	12
Buy 75 new hybrid buses	60/20 = 3	20%/4% = 5	30%/15% = 2	40%/40% =1	11
Create a busway	200/20 = 10	20%/20% = 1	30%/30% = 1	40%/8% = 5	17
Install a control system	20/20 = 1	20%/10% =2	30%/5% =6	40%/5% = 8	17

Note that the participants in this example were not debating the information that they were given. They did not dispute the costs of the proposed systems, the ability of each system to improve service or capacity, or the effect of improved service and higher capacity on ridership or emissions. Anyone who has been involved in evaluating such competing projects knows that there could well be extended debates about any or all of these matters. Still, even though all of the participants accepted the predictions of cost and impacts, it was possible to devise a scheme to make any one of the choices look the best.

There is a clear lesson from this case study. It is at best very difficult and more likely impossible to define a "correct" weighting scheme when there are competing options, multiple objectives, and differences in priorities among those who participate in making the decision. The best that can be done is to use some sort of participatory process to reach a consensus as to the weights that are used and the rankings that result. Extreme weights and contorted measurement schemes will be apparent to the majority of a diverse group of people, so if the measurement schemes and weighting options are presented fairly and subjected to general discussion, there will be some hope for reaching consensus.

Figure 1 South Station Bus Terminal, Boston

The bus terminal was constructed in the 1990s in order to replace an old, entirely inadequate terminal that was poorly located with respect to the subway system and the train stations. The new inter-city terminal was built right next to South Station, where it provides for easy connections with both transit and intercity rail.

The Panama Canal

The construction of the Panama Canal was one of the great engineering feats of the 20th century, culminating centuries of efforts to create more efficient transportation routes across this rain-soaked isthmus between the Atlantic and the Pacific. The case therefore begins with the 16th century search for routes from Europe to the Pacific, and it describes the development of roads and railroads as well as the eventual construction of the Panama Canal. The case also identifies the challenges facing the canal at the beginning of the 21st century, when the need for expanding capacity conflicted with heightened concerns for the environment and for social responsibility.

Early Routes Across the Isthmus

Columbus, sailing west in hopes of opening a trade route between Europe and Asia, instead ran into the Americas. While promising in terms of future development and precious metals, the Americas were not accepted as the limits of Spanish interest. The ultimate goal remained opening up a trade route to the civilizations of Asia.

Balboa, in 1516, was the first to establish a freight route across the isthmus. Having "discovered" the Pacific Ocean, with help from the local Indians, he of course wanted to continue his explorations. To do this, he needed to build ships on the Pacific side of the isthmus, and the trees required for the task grew only on the Atlantic side.

> *The terribly onerous labor of collecting the material and carrying it on their backs to its destination was imposed upon the Indians, of whom thousands were gathered together for the purpose, and impelled to the unaccustomed work by the merciless severity of their taskmasters. Many months were consumed in this grim struggle for a passage of the Isthmus, which, in many respects, foreshadowed the endeavors of the modern successors of these hardy pioneers. Hundreds of the wretched aborigines, Las Casas says their number fell little short of two thousand, lost their lives in the undertaking, but it succeeded, and four brigantines were carried piecemeal from sea to sea and put together on the Pacific coast.*[1]

Balboa's efforts were, for him at least, for naught; before he could depart on his expedition, he was tried, convicted, and executed on trumped-up charges by the jealous Spanish governor of the region. While exploration by sea was put on hold, the need for a "permanent highway to take the place of the Indian trails which were poorly adapted to the traffic which had now begun to move over them became apparent."[2] With great difficulty, a paved road wide enough for two carts was constructed in 1521 linking Old Panama on the Pacific with Nombre de Dios on the Atlantic. After about 10 years, the use of the route was modified to an intermodal route, with light sailing vessels leaving from Nombre de Dios and sailing up the Chagres in order to meet up with the road. By the end of the 16th century, the Atlantic terminus of the cross-isthmus road was shifted to Porto Bello. By then, this road was the "richest highway in the world", as it was the critical link between the Atlantic and Old Panama (the "most important Spanish City in the New World"), the mines of Peru, and the major regional fairs in Cartagena and Porto Bello.[3]

The Spanish continued to look for an all water route to the orient. In 1519, Magellan found the southern route to the Pacific, passing through the Straits of Tierra del Fuego. In 1522, using Balboa's vessels, Gil Gonzales sailed north, looking for a waterway, and eventually found Lake Nicaragua; in 1529, Diego Machuca explored the Lake and, with difficulty, navigated the San Juan River from the Lake to the Atlantic. Over the next century, this became an important commercial route for "vessels making ports in Spain, the West Indies and South America ... for more than a hundred years, a constant stream of gold, pearls, and other products of Spain's island possessions flowed across the Isthmus."[4]

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[1] Marshall, Logan, **The Story of the Panama Canal**, L.T. Meyers, 1913, p. 19.
[2] Marshall, op. cit., pp. 19-20.
[3] Marshall, op. cit., pp. 20-21.
[4] Marshall, op. cit., p. 19.

About this time Cortes established a transcontinental trade route across Mexico, from the mouth of the Coatzacoalcos River to the port of Tehuantepec on the Pacific, which was used as a trade route between Spain and the Americas as well as a link to the Philippines.

Military considerations put plans for a water route on hold. Philip the Second feared that a water route across the isthmus would simply give enemies easy access to Spain's new possessions. This policy lasted for two centuries. In the late 1700s, the possibility of a canal along the Cortes route was investigated by Manuel Galisteo. Although his conclusion was unfavorable, British engineers accompanying Galisteo felt the project was feasible. When war broke out with Spain, the British sent Captain Horatio Nelson to the region, who viewed his mission as follows:

> *In order to give facility to the great object of the government I intend to possess the Lake of Nicaragua, which for the present, may be looked upon as the inland Gibraltar of Spanish America. As it commands the only water pass between the oceans, its situation must ever render it a principal post to insure passage to the Southern Ocean, and by our possession of it, Spanish America is divided in two.*[5]

Nelson and his men indeed grabbed control of Lake Nicaragua, but climate and illness forced them out, and Spain retained control of the "canal region" at the beginning of the 19th century. New investigations by Humboldt generated interest in a canal, and in 1814 Spain passed legislation authorizing the construction of a canal. Before any work could begin, revolutions in South and Central America overthrew the Spanish dominance and

> *... opened up new possibilities in connection with the much-mooted question of a waterway and claimed the attention of capitalists and statesmen of all the commercial nations. From this time the matter is taken up with definiteness of purpose and never allowed to rest.*[6]

The United States officially became interested in 1825, when Secretary of State Henry Clay entered into negotiations with the Republic of Central America for building a canal across Nicaragua "the execution of which ... will form a great epoch in the commercial affairs of the whole world."[7]

In 1827, the Colombia commissioned J.A. Lloyd to study possible rail and water routes across the Isthmus of Panama. Lloyd considered plans for a canal to be premature and instead recommended an intermodal route combining water and rail to take the place of inadequate roads.

In 1838, a French company obtained a concession from what was now New Granada to construct highways, canals, or railroads from Panama to the Atlantic, by any feasible route. The pressure and interest was growing, but the difficulties were not yet well understood, and the costs of construction were greatly underestimated by all parties involved.

From the perspective of the United States, the strategic importance of the Isthmus changed immensely when California was acquired in 1848 as a result of the war with Mexico:

> "The requirements of travel and commerce demanded better methods of transportation between the Eastern States and the Pacific coast, but there were other reasons of a more public character for bringing these sections into closer communication. The establishment and maintenance of army posts and naval stations in the newly acquired and settled regions in the Far West, the extension of mail facilities to the inhabitants, and the discharge of other governmental functions, all required a connection in the shortest time and at the least distance that was possible and practicable. The importance of this connection was so manifest that the Government was aroused to actions before all the enumerated causes had come into operation, and negotiations were entered into with the Republic

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[5] Marshall, op. cit. p. 25.
[6] Marshall, op. cit. p. 27.
[7] Marshall, op. cit. p. 28.

of New Granada to secure a right of transit across the Isthmus of Panama."[8] [Report of the Isthmian Canal Commission. Washington, 1899-1901, cited in Marshall, p. 34].

A treaty was ratified with New Granada in 1848 for the Panama route in 1848. In 1849, a treaty was ratified with Nicaragua to allow construction of railroads, highways, or canals across Nicaragua. For many years thereafter, it appeared most likely that the United States, if it did build a railroad or canal, would choose the Nicaraguan route. And President Grant ensured the world that the United States was indeed interested in building a canal when he stated that "To Europeans, the benefits of and advantages of the proposed canal are great; to Americans they are incalculable."

The Panama Railroad

The idea of a railroad across Panama remained just that until the discovery of gold in California vastly increased the demand for transportation across the Isthmus. After earlier concessions expired without producing any construction, New Granada granted the railway concession to the Panama Railroad Company, which was incorporated in 1849 with strong financial backing from Wall Street. The concession gave the company a railroad monopoly across the isthmus and allowed it to sell its assets at a fair price to any company that was authorized to build a canal (since a canal, once built, would likely destroy the railroad, both financially and literally).

The benefits of a railroad were clear. For passengers, the railroad, once built, would cut the transit time across the isthmus from a hazardous five to ten days to a relatively luxurious couple of hours. For freight, the time savings were even greater, as months could be saved by not going around Cape Horn. For a trip from New York to San Francisco, the all water route was 13,000 miles, whereas the intermodal route via the Panama Railroad would be only 5,000 miles, a savings of 8,000 miles.

The engineering work for the railroad began in 1849, and construction was estimated to require two years and a cost of less than $2 million.[9] In fact, the first train operated across the 48-mile broad gauge[10] line in 1855 and the construction cost was more than $8 million, six times the initial estimates. In addition, the railroad acknowledged more than 1,200 fatalities in the work force, which averaged 5,000 men over the five years of construction. More likely, there were more than 6,000 fatalities from disease.[11]

The railroad was a financial success, with profits of 12 to 22% per year, i.e. $1 to $2 million annually. The railroad also reshaped the economic geography of Panama, as Colon, at the terminus of the railroad, replaced Porto Bello as the major Atlantic port. The financial success was to be expected given the potential for the railroad to capture the lion's share of the benefits of not having to ship around South America or to trek through the jungles of Panama. Passengers were quite happy to pay the fare of $25, and there were 40,000 passengers per year from 1856 to 1966.[12] Shippers were also willing to pay a bill that might be nearly as much per ton:

> *With the opening of the railroad, a large traffic across the isthmus sprang into existence and grew rapidly with the advance of time. The products of Asia and the countries upon the Pacific coast were carried [on the railroad] from Panama to Colon, there to be distributed amongst steamships making the ports of Europe, Canada, the United States and the West Indies. Moving in the reverse direction, goods from these countries reached, by the same trans-isthmian route, South and Central America and San Francisco. From the last named port, reshipment was made to the Pacific islands and points on the Asian mainland. A number of steamship lines made regular*

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[8] *Report of the Isthmian Canal Commission*. Washington, 1899-1901, cited in Marshall, p. 34.

[9] McCullough, David, *The Path Between the Seas: The Creation of the Panama Canal, 1870-1914*, Simon and Schuster, New York, 1977, p. 34.

[10] Gauge is the distance between the rails. Broad gauge, at five feet, is slightly wider than the standard rail gauge of 4 feet 8.5 inches, which reputedly can be traced back to the gauge of wagons used in Roman times. The persistence of the standard gauge from ancient times reflected the need for wagons to fit the ruts found in dirt and gravel roads.

[11] McCullough, op. cit., p. 37

[12] McCullough, op. cit., pp. 35-36.

calls at the terminal ports of the railroad. The line occupied a commanding position as the essential link in this chain of traffic, and took full advantage of the fact. Its charges were exorbitant and its profits enormous for many years. Its rates were based on, in general, fifty per cent of the through tariff. For instance, of the total cost of shipping goods from New York to Valparaiso [in Chile], one half represented the charge of the railroad company for its share of the carriage. For many years the road carried enormous quantities of coffee to Europe. The through rate was about thirty dollars per ton. The railroad company received fifteen dollars and the two steamship companies that handled the goods divided a similar sum. [13]

In its first six years of operation, the Panama Railroad had cumulative profits of more than $7 million, nearly recouping the entire construction cost. At one point, the stock price of the Panama Railroad Company reached $295 per share, the highest on the NY Stock Exchange for a market valuation of $21 million and an indication to potential investors of the financial possibilities of a transcontinental connection.[14] In 1879, the railroad was offered for sale to the [French] Panama Canal Company for $14 million; 6/7 of the stock of the company was eventually sold to the Panama Canal Company for $18.6 million.[15]

When the United States took over the construction of the Canal from the French in 1904, it acquired the railroad as well. Shippers took the change in ownership as an opportunity to challenge the monopolistic pricing practices of the railroad. For example, the railroad had a contract that gave the Pacific Mail Steamship Company the exclusive right to issue through bills of lading from San Francisco to New York; all other steamship lines would have to pay full fare for the local rail move. When the US took over, the monopolistic rates were replaced with rates designed only to provide a fair rate of return over costs.[16] This change in pricing policy ended the period of independent prosperity for the railroad.

However, the Panama Railroad's finest hour was yet to come. To construct the canal required the extensive use of the railroad, but the railroad first had to be moved, since much of it would otherwise be flooded by the creation of Lake Gatun, a critical step in the construction. The cost of the new, double track line was $8.9 million, i.e. roughly the same as the cost of the original line. During the height of the canal construction, the line handled 700 to 800 dirt trains daily, each consisting of a locomotive and 18 flat cars with a total load of 500 tons. The peak year was 1910, when the line moved approximately 300 million tons of freight, a truly phenomenal amount that is roughly 20% of the record levels of tonnage handled by the entire US rail system (first during World War II, but not again until the late 1990s). Despite tremendous technological advances in both track and equipment, even the highest density lines in the United States (and in the world) carried only half that amount of tonnage at the beginning of the 21st century.[17]

The French Effort

The first serious effort to construct a trans-isthmian canal was initiated by the Panama Canal Company, a French company headed by Ferdinand de Lesseps, the man who had conceived, organized, and completed the construction of the Suez Canal. A number of engineering conferences had been held to debate the route, the nature of the canal, and the resources required. Panama was the route favored by de Lesseps, who also insisted on a sea-level canal. The construction time for and the cost of constructing the canal were variously estimated as two years and $100 million (by a contractor eager to do the job), eight years and $168 million by a national technical commission, and twelve years and $214 million by the Paris Congress. De Lesseps, in promoting the project, chose a figure of $131 million. The canal was clearly going to be much more expensive than the railroad!

De Lesseps estimated the first year's traffic as 6 million tons, which would assure revenue of $18 million (at $3 per ton). Since a sea-level canal would have low operating costs, most of the toll revenue would be expected to be profit.

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[13] Marshall, op. cit., pp. 52-53.
[14] McCullough, op. cit., pp. 35-36.
[15] Marshall, op. cit., p. 109.
[16] Marshall, op. cit., pp. 55-56.
[17] Association of American Railroads, *Railroad Facts*, various editions.

Hence, according to the company's statements, the project would return approximately 10-15% once it opened for business.

Writing in 1913, just before the canal finally opened, Marshall (and the whole world) knew that the cost estimates were way too low. He also stated that the revenue estimate "was claimed to be a very conservative assumption, whereas, it was in reality almost beyond the possibility of realization."[18] Given that the railroad freight charge was as much as $15 per ton, a price of $3 per ton might well have seemed reasonable at the time. However, by 1913, with the United States running the railroad, the rates were no longer so extravagant and, with larger ships operating, the prices of ocean transport had also fallen. Marshall may also have been concerned with the projected volume of traffic. (In actual fact, the canal handled 4.9 million long tons of cargo and earned revenues of $4.4 million in its first full year of operation in 1915; by 1923, with cargo of nearly 20 million tons, revenues reached $17.5 million.[19]

The canal was viewed as a tremendous financial opportunity, and the effort was therefore undertaken by the private sector. The Panama Canal Company was formed in 1879 with an initial capitalization goal of $80 million and, given the general excitement, double that amount was raised very quickly.

Construction began in 1883, and troubles were almost immediately encountered. The amount of excavation required was more than expected, the soil conditions were much softer and more unstable than anticipated, and the 20-foot difference in tides between the Pacific and the Atlantic was recognized as a major problem. Yellow fever and malaria took a fearful toll among the workers and their families, and the project took on the aspect of a military campaign.

Nevertheless, de Lesseps still expected the canal to be completed by 1888. His engineers were more realistic, and they recommended that a lock canal be built to reduce the need for excavation. De Lesseps, however, refused to break his promise for a sea-level canal. Marshall emphasizes that this particular dispute concerned matters of financial rather than engineering feasibility:

> *The point of their decision was whether a sea level canal could be constructed at a cost and in such time as to make its operation a profitable business for the shareholders. Time, of course, is a great factor in the cost of an operation involving hundreds of millions. Interest increases at an enormous rate during the later years. Therefore, considerations which would preclude the pursuit of a project solely contemplating commercial results might not be of sufficient weight to deter a government from following the same lines. ... Even though the operation of the canal should fail to return any interest upon the money invested, the Government might well consider itself fully compensated for the outlay by the political advantages secured, the great savings in the movements of warships, and other desiderata.* [20]

The labor force was nearly 10,000 men by 1887; the standard wage was $1.50 per day for about 20 days per month. The payroll for laborers was therefore on the order of $5 million per year. Another 1,500 or so company employees added several more million to the payroll, and costs and transportation of machinery averaged several million per year. The big problem, however, was that the costs were rising and the possibility of ever making a profit was disappearing. By 1889, the company had raised (and spent) $265 million and was looking for more than $100 million more. Interest charges were already $16 million per year, and it was apparent that they would rise to more than $30 million by the time the canal was opened (assuming that it could be completed). Since revenues were projected to be only $18 million, the prospects were nil, and this was evident to everyone with any money to invest. A final effort to raise $160 million in "lottery bonds" that would provide 4% interest plus participation in semi-monthly drawings for cash prizes was approved by the government, but only about $60 million was raised. This was the last hope for the French effort,

[18] Marshall, op. cit., p. 98.
[19] Office of Executive Planning, Panama Canal Commission, Historical Reports - Panama Canal Traffic - Oceangoing Commerce.
[20] Marshall, op. cit. p. 104.

and the Panama Canal Company went into bankruptcy in 1889.

At this point, if the canal project were to be terminated, the company and its shareholders would lose everything. Since the work completed at that time was valued at about $100 million, a major effort was made to reorganize the effort in order at least to salvage this value. Colombia, which also stood to gain from the construction of the canal, was also very anxious for work to proceed. The result was that a new company, the New Panama Canal Company, emerged from the chaos of the old and was given an extension until 1904 to complete the canal.

At this time extensive engineering surveys were conducted by a commission established to review the status of the canal. The commission believed that "a lock canal might be completed in eight years at a further cost of $100 million." The New Panama Canal Company therefore studied how such a canal might be built.

They also saw another way to escape from their problems: sell their concession, equipment, and the completed portions of the canal to the United States, which at that time was pursuing the possibility of digging a canal in Nicaragua. After several years of negotiations and study, the New Panama Canal Company offered to sell everything to the US for $109 million.

The Isthmian Canal Commission, in its report to President Roosevelt, set the value of the property at only $40 million and concluded that the Nicaragua route would actually be the "most practical and feasible route". Since there was only one possible buyer for the property, the New Panama Canal Company, in a panic to salvage something, quickly reduced its asking price to $40 million. In turn, the Isthmian Canal Commission revised its opinion concerning the route on the grounds that Panama was preferable at the lower price.

This deal cleared the way for the US to take over the construction of the canal, although not before a good deal of political theatre. Suffice it to say that Colombia attempted to raise the annual fee that it would collect, that the US balked, and that Panamanian citizens, fearful of losing the canal to Nicaragua, declared the independence of Panama. McCullough describes the intrigue in absorbing detail; Joseph Conrad describes the emotions of times in his great novel "Nostromo," which was modeled on these events.

The U.S. Effort

When the US took over, they had to deal with several major design issues related to the cost, capacity, and performance of the canal:

- Sea level canal vs. a lock canal
- The number and height of the locks
- The length and the width of the locks
- The height of the canal above sea level and the size of the lake

They also had to deal with the tropical illnesses. Fortunately, mosquitoes had been identified as the transmitters of malaria and yellow fever, so it was possible to formulate and implement a strategy for eliminating mosquitoes as a way of controlling disease. That fascinating story is covered by McCullough; suffice it to say that first priority was given to eradicating the mosquito within the Canal Zone, and the diseases were successfully eliminated.

<u>A Sea Level Canal vs. a Canal with Locks</u>

A sea level canal would have the advantage of lower lock cost and easier operations, but it would require more excavation. Since the tides on the Pacific vary by 20 feet from high to low, a tidal lock would be needed on that end of the canal even for the sea level route (otherwise tidal currents would be too strong to safely operate large ships through the canal). A lock canal would reduce the excavation costs and reduce the time required to open the canal to operations. Like de Lesseps, most people wanted a sea level canal, if it were reasonably possible to construct one.

President Roosevelt stated the case elegantly, in language that could readily be adapted to the evaluation of the alternatives being considered for any mega-project:

> *I hope that ultimately it will prove feasible to build a sea-level canal. Such a canal would undoubtedly be best in the end, if feasible, and I feel that one of the chief advantages of the Panama Route is that ultimately a sea-level canal will be a possibility. But, while paying heed to the ideal perfectibility of the scheme from an engineer's standpoint, remember the need of having a plan which shall provide for the immediate building of the canal on the safest terms and in the shortest possible time.*
>
> *If to build a sea-level canal will but slightly increase the risk, then of course, it is preferable. But if to adopt a plan of a sea-level canal means to incur hazard, and to insure indefinite delay, then it is not preferable. If the advantages and disadvantages are closely balanced I expect you to say so.*
>
> *... Two of the prime considerations to be kept steadily in mind are: 1. The utmost practicable speed of construction. 2. Practical certainty that the plan proposed will be feasible; that it can be carried out with the minimum risk.*[21]

The Number and Height of Locks

The commission recommended a sea-level canal, but the American members filed a minority report recommending a lock canal that would reach 85 feet above sea level. Congress accepted the minority report, and that was the basis for what was built.

The number and height of locks represents a balance among lock technology, operating costs, and construction costs. The height of the lock chamber and the mitre gates must be several feet higher than the draft of the largest ships (close to 40 feet) plus the height of the lift plus several feet of water under the ship plus a foot or two above water level when full. For an 85 foot lift, this would require two locks with a lift of 42.5 feet each or three with a lift of 27.4 feet each; even the smaller lift would be higher than any other locks yet constructed, and the required chambers and gates would be about 80 feet high. A three lock system was selected for each end of the canal.

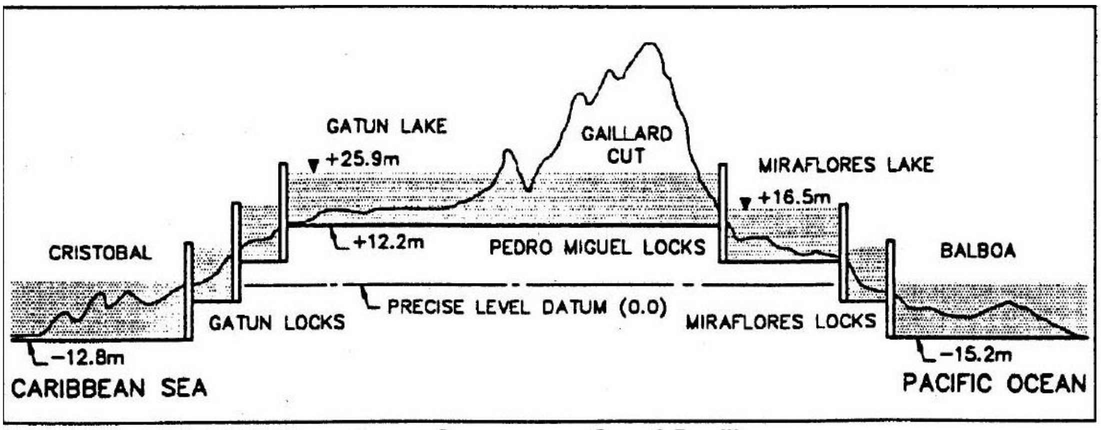

Figure 1 A Cross-Section of the Panama Canal[22]
Three sets of locks on each side bring ships up to the level of Lake Gatun.

[21] President Theodore Roosevelt's instructions to the International Board of Consulting Engineers that was assembled to consider the principal problems in construction a canal, September, 1905 [Marshall, p. 134].

[22] The Commission for the Study of Alternatives to the Panama Canal, "Operating Characteristics and Capacity Evaluation Study", May 1993.

The Length and Width of the Locks

The goal for the canal was to handle the largest ships planned as of that time, which were in fact battleships. The original dimensions of the lock chambers were to be 900 feet long by 95 feet wide, but the Navy requested an increase to 1000 feet long by 110 feet in order to allow for larger ships in the future. There was a debate about whether or not to go to the larger size. Colonel Goethals, in charge of the canal construction, advanced the case for staying with a 100 foot beam:

> *The present lock designs provide intermediate gates dividing the locks into lengths of 600 and 400 feet. About 98 per cent of all ships, including the largest battleships now building, can be passed through the 600-foot lengths, and the total lock length will accommodate the largest commercial vessels now building, which, I believe are 1,000 feet long and 88 feet beam. It is true that ships may increase in size so as to make the present locks obsolete, but the largest ships now afloat cannot navigate the Suez Canal, nor the proposed sea level canal at Panama. It must also be remembered that the commerce of the work is carried by the medium-sized vessels, the length of only one of the many ships using the Suez Canal being greater than 600 feet."*[23]

Marshall, who was writing in 1913, was happy to report that Goethals was overruled and the lock dimensions were set at 1000 by 110 feet:

> *Our new battleships have a beam of 97 feet and upwards, which will leave a clearance in the lock chambers of less than 13 feet in all, or about 6 feet on either side. Commercial vessels now built, and others whose keels have been laid, have a beam of 96 feet, so that it is quite possible that the locks may prove to be too narrow before they are found too short.*

Water Requirements

The height of the canal above sea-level and the size of the locks represent a balance between the availability of water and the size of ships that can be handled. Larger locks require more water, but they can handle larger ships. If the canal is higher, and the chambers are deeper, then more water is also required. A canal requires a source of water, such as a large lake, that will be sufficient to operate the locks year round. If there is a distinct dry season, then the lake ideally would have enough reserve capacity to operate throughout the dry season without affecting operations. Given the size of the lock chambers, a great deal of water is used for each lockage. The basic requirements are that the total water lost through lockages be less than the average annual inflow to the lake and that the surplus water in the system be sufficient at the beginning of the dry season to last until the rains return.

A height of 85 feet above sea level was selected for Lake Gatun, the 164 square mile lake that was created by flooding the Chagres River (Figure 2). This lake impounded water from a basin of 1,320 square miles that "enjoyed" extremely heavy tropical rains from early may through the beginning of December. The amount of water was quite considerable. In the 22 years before the opening of the canal, the outflow of the river ranged from a low of 132 billion cubic feet in 1912 to a high of 360 billion cubic feet in 1910, nearly double the 183 million cubic feet contained by the lake when full. Marshall used the 1912 season to illustrate the adequacy of the lake for supporting the canal operations. If Lake Gatun enterered the rainy season on December 1 with an elevation of 87 feet and operated with 48 lockages per day, then the lake level would decline to 79.5 feet by May 7th, when the rains returned. With this water level, there would be 39 feet of water in the cut, which would provide sufficient depth for navigation (for the ships of that time). Allowing for evaporation and seepage, there would still be enough water for 41 lockages a day, which was more than could actually be done because of the time required per vessel. The width of the cut was originally set at 200 feet, but this would not allow enough room for two large ships to pass. The width was therefore increased to 300 feet. A wider cut required considerably more excavation, but also increased canal capacity.

[23] Quoted in Marshall, op. cit., p. 186.

Figure 2 Lake Gatun
A vast supply of water must be available to allow operation of the locks. Lake Gatun was formed by damming the Chargres River, using the material excavated from the cut to create the dam. Stumps from the forest that was submerged under the lake are still visible, and divers visit the remains of the old Panama Railroad.

Construction Cost and Pricing Policy

The Panama Canal was the largest project undertaken by the U.S. up until that time. After the U.S. had been at work for 3 years, it was estimated that the cost would be $375 million, including original payments of $10 million to Panama and $40 million to the French company.[24] This proved to be accurate, as the actual construction cost was $352 million for the U.S. portion of the work (and a total of $639 million for the French and American efforts). The loss of life associated with the construction was staggering. Disease and accidents claimed 5,609 lives between 1904 and 1914, but this was far better than the French experience, as they lost approximately 20,000 people. If the French companies and their prospective stockholders had understood the financial and the human costs, they never would have been able to raise the money to begin. If the US Congress had realized the magnitude of the effort in 1904, they might also have balked.

It is an irony of history that the first vessel went through the canal on August 3, 1914, the day that World War I began. Though completed 6 months ahead of schedule, it would be 10 years before traffic would grow to the expected levels of 5,000 ships per year. Toll revenues reached $27 million in 1929 and 1930, but did not reach this level again until 1953, because of the effects of depression and another world war (Table 1).

The U/S. Congress required the Panama Canal to operate on a break-even basis, i.e. it had to cover both operating and capital costs from tolls. This prevented the Commission from incurring debt or from achieving exorbitant profits. It also meant that there was no attempt to recover the capital costs of constructing the canal. If the Canal had been financed through private sources at 5%, the interest costs during the 10-year construction period would have added well over $100 million to the initial cost, and the carrying charges would have been on the order of $25 million

[24] McCullough, op. cit., p. 610.

annually thereafter. Given the tremendous savings in distance, it is quite possible that tolls could have been raised to cover this cost during good times, but it is also quite likely that the Canal would have gone bankrupt during the wars or the depression.

During World War I, the Canal played no strategic military role, as the first flotilla of warships to transit the canal was composed of ships returning home after the war. In World War II, the canal played a major role, as it allowed rapid deployment of ships from the Atlantic to the Pacific theatre of operations.

In 1996, the Canal handled 13,536 ocean-going commercial vessels carrying 198 million long tons of cargo and earned revenues of $483 million from tolls. While the average toll per ton remained less than the $3 projected by de Lesseps, the total tonnage and total revenue greatly exceeded his projections of 6 million and $18 million respectively. The cumulative toll revenue from the opening of the canal reached $9 billion by 1997.

Table 1 Oceangoing Traffic Through the Panama Canal, 1915 - 1996

Fiscal Year	Transits/Year	Transits/Day	Cargo (Long Tons)	Toll Revenue ($millions/yr)	Revenue/Ton
1915	1058	2.9	4.9	$4	$0.90
1920	2393	6.6	9.4	$9	$0.91
1925	4592	12.6	24.0	$21	$0.89
1930	6027	16.5	30.0	$27	$0.90
1935	5180	14.2	25.3	$23	$0.92
1940	5370	14.7	27.3	$21	$0.77
1945	1939	5.3	8.6	$7	$0.84
1950	5448	14.9	28.9	$24	$0.85
1955	7997	21.9	40.7	$34	$0.83
1960	10795	29.6	59.3	$51	$0.86
1965	11834	32.4	78.6	$65	$0.83
1970	13658	37.4	114.3	$95	$0.83
1975	13609	37.3	140.1	$142	$1.01
1980	13507	37.0	167.2	$292	$1.75
1985	11515	31.5	138.6	$299	$2.15
1990	11941	32.7	157.1	$354	$2.25
1995	13459	36.9	190.3	$460	$2.42

Source: data prepared by Office of Executive Planning, Panama Canal Commission, May 8, 1997.

Transfer of the Canal to Panama

The operation of the canal was transferred to Panama on December 31, 1999, culminating a 20-year transition period in which responsibility was shifted from the US to Panama. In anticipation of the transfer, the Panama Canal Commission and the US Army Corps of Engineers conducted a thorough inspection of the canal and the locks. In general, the locks and the canal were believed to be in excellent condition, and programs were in place for maintenance and rehabilitation of the major components of the canal.

A greater concern was the capacity of the canal, both in terms of the size of ships that can fit through the locks and the number of ships that can be handled on a sustainable basis. In 1996, the canal handled a record-breaking 37.5 ocean-going ships per day, which caused the Canal Waters Time (the time from arrival at one end of the canal until departure from the other end) to rise from the target level of 24 hours to more than 30 hours. This increase in delay signaled potentially serious capacity problems for the canal.

Issues for the 21st Century

Post-Panamax Ships

Aircraft carriers and oil tankers were the first ships that exceeded the dimensions of the locks. In the 1980s, a new class of containerships (Post-Panamax) was designed for use in trans-Pacific operations; to reduce the cost per container, these ships were built wider than the 110 feet that could go through the canal. Even larger ships were being planned for the future. Since container shipping was one of the fastest growing areas of commerce, the existence of a large number of Post-Panamax ships was a strategic concern for the canal.

Increasing the Operating Capacity of the Canal

The capacity of the locks is limited by the average time required to move a large ship through one chamber, which is about an hour, suggesting a maximum service rate of 2 vessels per hour (since there are two parallel channels in each set of locks). Additional time is also required to position ships as they arrive at the locks and the locks must periodically be closed for routine inspections and maintenance, so the sustainable capacity drops to 37-38 vessels per day.

Figure 3 Pedro Miguel Lock

Note that the locomotives that are attached by cables to the container ships. The ship moves through the lock under its own power, while the ship's pilot directs the locomotive engineers to tighten or loosen the cables in order to keep the ship properly aligned. Also note how little room there is to spare between the ships and the side of the locks.

Some efficiency can be gained in lockages by increasing the number and reliability of the specialized railroad locomotives that are used to guide ships through the locks. Several minutes can be lost in repositioning locomotives when several large ships are going through simultaneously. The Panama Canal Commission therefore authorized $90 million to increase the fleet from 82 to 110 locomotives.[25]

Widening the Gaillard Cut

The Gaillard Cut was originally a minimum of 91.5m wide for its entire 12 km length. Widening to 152m, begun in the 1930s and completed by the early 1970s, allowed unrestricted two-way traffic for almost all ships operating at that time. However, by the 1980s, a substantial and growing number of the vessels using the canal were Panamax ships that were too large and unwieldy and too valuable to risk passing in the Gaillard Cut or operating in the Cut after dark (Table 2). It was necessary for fleets of these large ships to operate single file through this nine-mile stretch during the daylight. This complicated scheduling and restricted capacity of the canal.

Table 2 Panama Canal Traffic (Long Tons), by Commodity Group, 1994-1996

Commodity Group	1996	1995	1994
Grains	42.34	44.07	34.07
Petroleum and petroleum products	32.77	27.48	26.96
Containerized cargo	25.62	24.91	22.44
Nitrates, phosphates and potash	15.94	15.91	15.44
Coal and coke (excluding petroleum coke)	11.38	11.32	9.34
Ores and metals	11.52	10.76	10.10
Lumber and products, including pulp wood	11.03	10.71	9.47
Chemicals and petroleum chemicals	11.37	10.11	9.71
Manufactures of iron and steel	8.35	9.17	7.85
Canned and refrigerated foods	6.95	6.86	7.00
Minerals, miscellaneous	6.87	5.43	5.79
Other agricultural commodities	5.16	4.92	4.54
Machinery and equipment	1.93	2.14	2.05
All other	6.62	6.52	6.61
Total	198.07	190.3	170.54

Source: Office of Executive Planning, Panama Canal Commission, Report TRA 1-3, Nov. 18, 1996

A widening program was begun during the mid-1990s and was initially scheduled to be completed by 2005. At a cost of $200 million, this program increased the Cut to 192m in straight sections and up to 222m in curves in order to allow bi-directional operation of Panamax vessels, which would increase the capacity to approximately 42 ships per day. The program was spread out over so many years in order to allow the work to be done largely with the existing workforce and equipment. When the number of Panamax vessels grew rapidly during the mid-1990s, the capacity problem became more critical, and the program was accelerated.[26]

System Control

A $20 million effort to develop a computerized scheduling system enabled higher utilization of the cut by adjusting the sequence of large ships through the system. These management efficiencies increased overall capacity by 1 ship per day.

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[25] Spillway Newsletter, *Canal accelerates modernization plan, improvement work*, Panama Canal Commission, September 20, 1996.

[26] Panama Canal Commission, *Gaillard Cut Widening Program,* 1996.

Figure 4 Widening the Gaillard Cut, 1996

This process required dredging to widen the canal, cutting back the hillsides along the cut, and providing sluices to channel water from heavy rains into the canal. The process could be accelerated by devoting more resources to the task.

Expanding the Canal

By the mid-1990s, it was evident that the canal would have to be expanded in order to handle the demand projected for the first half of the next century. Even the pessimistic scenarios for growth forecast traffic growing to more than 50 vessels per day by 2050, which is at least 10 to 20% above what the above improvements could allow on a sustainable basis.

Several major options were considered, including adding a third set of locks, replacing the existing locks with larger locks, and construction of a new sea-level canal (Table 3). A sea-level canal was estimated to cost on the order of $12 billion to construct, and it would require large ships to move single file through the canal. A sea-level canal would require carving out an entirely new route. Moreover, parts of the route would be only one lane wide, so that the largest ships would be unable to pass. Hence, the capacity of the new canal would be only half the capacity of the existing canal, and building such a canal would only provide a 50% increase in overall capacity. Adding a new set of locks, even a much larger set of locks, would be less costly and would provide a greater boost in capacity. With the ability to handle larger ships, canal capacity would be increased by 70% at a cost estimated at about $2 billion by the US Army Corps of Engineers in 1995. The third set of locks was therefore selected as the most cost effective way to increase capacity, and work began on this project after the Canal was transferred to Panama. The third set of locks was finally completed and opened to traffic in 2016.

Table 3 Conceptual Alternatives to the Existing Canal[27]

	Existing Canal	High-Rise Locks (a)	Low-Rise Locks (b)	Sea-Level (c)
Vessel Size (dead wt. tons)	65 million	250 million	250 million	300 million
Rise (feet above sea level)	85	90	55	0
Number of lifts	3	2	1	0
Number of lanes	2	2	2	Half with 1; half with 2

a) This option would utilize taller gates so that only two lifts would be required; a somewhat deeper lake would necessitate a higher rise. (One variation of this option would be to keep the existing locks and add a third set that would be able to handle larger ships, thereby increasing capacity 70%.)

b) This option would require a new location for the locks, with only a single lift required.

c) This option would require an entirely new sea-level canal) that would still require locks because the great difference in tides would result in unacceptably rapid currents through the canal.

[27] The Commission for the Study of Alternatives to the Panama Canal, "Operating Characteristics and Capacity Evaluation Study", May 1993.

Case Study
Pearl River Delta: "More than a Bridge"

The greatest mistakes in project evaluation are likely to be made very early by defining projects too narrowly or incorrectly. Likewise, the greatest contributions to the success of a project may come from people who view possibilities from a broad perspective. The context within which such a project is initially viewed may dramatically limit or expand the long-term costs and benefits to an entire region of a country.

This case study shows how an experienced interdisciplinary team framed the issues and opportunities associated with a major infrastructure project within one of the world's largest, multi-centric regions, namely the Pearl River Delta in China. The team participated in the earliest stages of public debates concerning the possibility of bridging the Pearl River estuary. The basic idea had been around for at least two decades, but there was as yet no commitment to any particular plan. It was therefore possible to introduce new ideas, to debate the justification of the project, to explore related issues, and to prepare a broader context for evaluating the project. What seemed to be a question of how to pay for a bridge turned out to be a question of how the construction of one or more bridges could influence traffic management, economic development, open space, water quality, and other factors within the populous Pearl River Delta region of China.

Background

The Pearl River Delta is one of the most densely populated regions in the world. Guangzhou, at the head of the Delta, is a city of 15 million people; Hong Kong, on the eastern edge of the Delta, is one of the most prosperous cities and largest ports in the world; the region includes Macau on the west side of the delta and a half dozen other major cities with more than a million people each. Overall, more than 40 million people live in this region. The institutional structure of the region is complex, as Macau and Hong Kong are Special Administrative Regions (SARs) and Zhuhai and Shenzhen are Special Economic Regions (SERs). While it is all part of China, the region has complex boundaries and customs regulations. At the time of the study, economic growth in the region was expected to continue its torrid pace as the various pieces of the region become more fully integrated.[1]

By 2002, proposals had originated both from Hong Kong and China to build a bridge and/or a tunnel across the Pearl River in order to integrate Hong Kong with the West Delta. The proposals sparked debates about the need and justification for such a project, the nature and location of the crossing, the financing of the project, and the potential social and environmental impacts. The Hong Kong 2022 Foundation asked an interdisciplinary team from M.I.T. to provide guidance in identifying and assessing the major issues and constraints that should be considered in assessing any proposal for creating a link between Hong Kong and the west side of the delta. The foundation was not at that time interested in specific designs.

The team was headed by Professors Tunney Lee and Ralph Gakenheimer of M.I.T.'s Department of Urban Studies and Planning and Nien Dak Sze, chairman of AER, Inc, a consulting firm with experience related to major projects in Hong Kong. Fred Salvucci, senior lecturer in the Department of Civil Engineering was a key member of team; his unique experience included two terms as Secretary of the Executive Office of Transportation and Construction in Massachusetts at a time when the state initiated several major transit and highway projects. Salvucci and Lee both had a long history in transportation planning in Boston, going back to the early 1970s when Massachusetts decided to scrap the plans for ever more highways and to develop a more balanced transportation system.[2]

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[1] Enright, M, K.M. Chang, E. Scott, and W.H. Zhu, "Hong Kong & the Pearl River Delta: The Economic Interaction", The 2022 Foundation, Hong Kong, 2003

[2] Other members of the team included Ken Kruckemeyer (lecturer at MIT and former engineer with EOTC; expert in bridge design and neighborhood impacts of transportation projects) and Gerry Flood (expert in mapping and computer graphics). The team was

The study revolved around a series of informal weekly or bi-weekly meetings that allowed a great deal of open-ended discussion about options, issues, strategies for projects, and schemes for presenting our ideas. Articles about the project, which appeared regularly in the Chinese press, were circulated to the team.

It quickly became evident – based upon comparisons with similar projects successfully completed around the world - that it would be possible to build a bridge across the Pearl River. Depending upon the location of the project, a tunnel would be desirable in order to avoid any interference with shipping to and from the port of Hong Kong. It was also evident that the economic benefit would like be very high, so that it would be possible to justify the project either from the perspective of the public sector (effects on gross domestic product and regional integration) or the private sector (profitability based upon toll-based financing). A major concern was that government agencies would move too quickly to begin construction of a project without clearly understanding the range of issues and impacts that were relevant. It would be easy to build and finance a bridge that would not be close to the best size, in the best location, with the best design, with the best integration with other infrastructure projects, or with the best environmental and social impacts.

The team members did not have the data, the analytical resources, or the inclination to conduct detailed traffic analyses or to pursue any technical or economic analysis. Instead, they used international examples, their combined experience with major projects, their knowledge of transportation systems, and straightforward analysis to highlight what they felt were key issues.

- The bridge was feasible, as bridges and tunnels of similar length had been constructed elsewhere in the world (Table 1).
- Since the bridge/tunnel would provide a much shorter route between two very densely populated areas, the Pearl River Delta offered an excellent opportunity for constructing a bridge.
- The debate should consider the location of the bridge, the possibility of have a Y-shaped bridge (i.e. one that links two cities on one side with one on the other side), a double-Y, or two separate bridges.
- The bridge should be considered as a key link in a multi-centric region, with implications for traffic management, investment and economic growth throughout the region.
- "More than a bridge:" the project should be reviewed in light of opportunities for such things as renewable energy (wind power or solar farms located on or near the bridge), development of existing islands, the creation and development of new islands, and the location of piers and new islands so as to promote river flow and prevent silting.

Table 1 Examples of Long Bridges and Tunnels

Bridge or Tunnel	Length	Cost	Toll
Chunnel (rail tunnel connecting Great Britain and France)	50 km	$21 billion	$75
Lake Pontchartrain Causeway (causeway connecting New Orleans to points north of the city)	39	$0.06 billion	$1.50
Chesapeake Bay Bridge/Tunnel (connecting Norfolk VA with the Eastern Shore of VA)	28	$0.4 billion	$10
Oresund (Denmark – Sweden)_	16	$2.4 billion	$32
Tokyo Bay Aqualine (connecting Tokyo with the relatively undeveloped eastern side of Tokyo Bay)	15	$11.7 billion	$20

supported by graduate students Yanni Tsippis, Dalong Shi and Mark Schoffield in MIT's Transportation program As a member of the team, my role was to provide support in two areas, project evaluation and freight transportation. As a participant, I was able to observe, first-hand, how discussions and ideas came up, mutated, and eventually became part of a consensus about what could or should be done and what should not be done.

The research produced a highly polished report that was laden with pictures and figures with great visual appeal.[3] The report, which included poster-sized pullouts, was aimed at conveying information and insights very quickly. The report was presented at a workshop held at Hong Kong University on March 25-26, 2003. The workshop was organized by the sponsor, the 2022 Foundation, as a means of promoting discussion among government officials, representatives of non-government organizations (NGOs), and private sector business leaders from both China and Hong Kong. The study helped promote awareness of the wide range of benefits and options and of the importance of integrating the bridge project with other regional infrastructure planning efforts related to economic development, transportation systems, and the environment.

How the Team Did Its Work

Time is necessary for gestation of ideas. As the team members met regularly over a period of eight months, they evolved an ever more complex view of the project, along with an increasingly coherent story to tell about the project. The process involved brainstorming, contemplation, debates, re-consideration of issues, introduction of new issues and perspectives, preliminary analysis, and more debates. The idea of using international comparisons came up in the team's first meeting, in May 2002. The major options for the alignment were identified by August, and the possibility of building two bridges was broached in September. The team did not seriously consider the importance of viewing the bridge as a key link in a multi-centric region until early in 2003. The role of tolls was discussed in July 2002, then visited again in February as part of a broader discussion of traffic management within the region. The team referred to environmental concerns at the outset, but eventually had more specific ideas about leaving more open space on the east side, about bypassing the coast when developing the west side, and integrating the bridge with the efforts to clean up the estuary. The team also discussed the aesthetics of the bridge, including an idea that the bridge could be designed so as to resemble a dragon when viewed from the air – with the ability to have fireworks propelled from the Dragon's mouth. The result was not something that any team member could have created individually, nor was it something that the entire group could have created in a short time.

While the team was developing its view of the project, the South China Morning Post published many articles that provided information and opinions concerning the economic potential for the bridge, financing ideas, and environmental considerations, especially issues unique to the region. Major potential benefits of the project included integration of Hong Kong within the Pearl River Delta region and strengthening the ability of that region to compete with other regions in China, notably Shanghai. Better connectivity would promote regional economic growth and help maintain the role of Hong Kong and the region as an international logistics center.

The results of the interdisciplinary study did indeed broaden the debate. One impetus for the study was a specific proposal by a Hong Kong businessman, Sir Gordon Wu, who had offered to build a bridge at no cost to the government. His company would build the bridge and finance the costs by pledging toll revenues to cover debt servicing. He indicated that the public sector would only have to cover the cost of a 9-km connecting road. The early articles referred to "the bridge" and "the route" and whether or not a public subsidy would be needed. The team's report, as described above and as illustrated in Figure 1, widened the debate and specifically emphasized the need to consider other uses for tolls (traffic management and financing for other parts of the system, not just financing for the bridge), the need to maximize the public benefits of the bridge, and the potential for tying the bridge project into comprehensive plans for improving the region's infrastructure and environment.

[3] Martland, Gakenheimer, Kruckemeyer, Lee, Murga, Salvucci, Shi, Sze, Gongal, Flood, Imai, and Won, "Linking the Delta: Bridging the Pearl River Delta", The 2022 Foundation, Hong Kong,2003 (www.2022foundation.com)

Lessons Learned From the Pearl River Delta Study

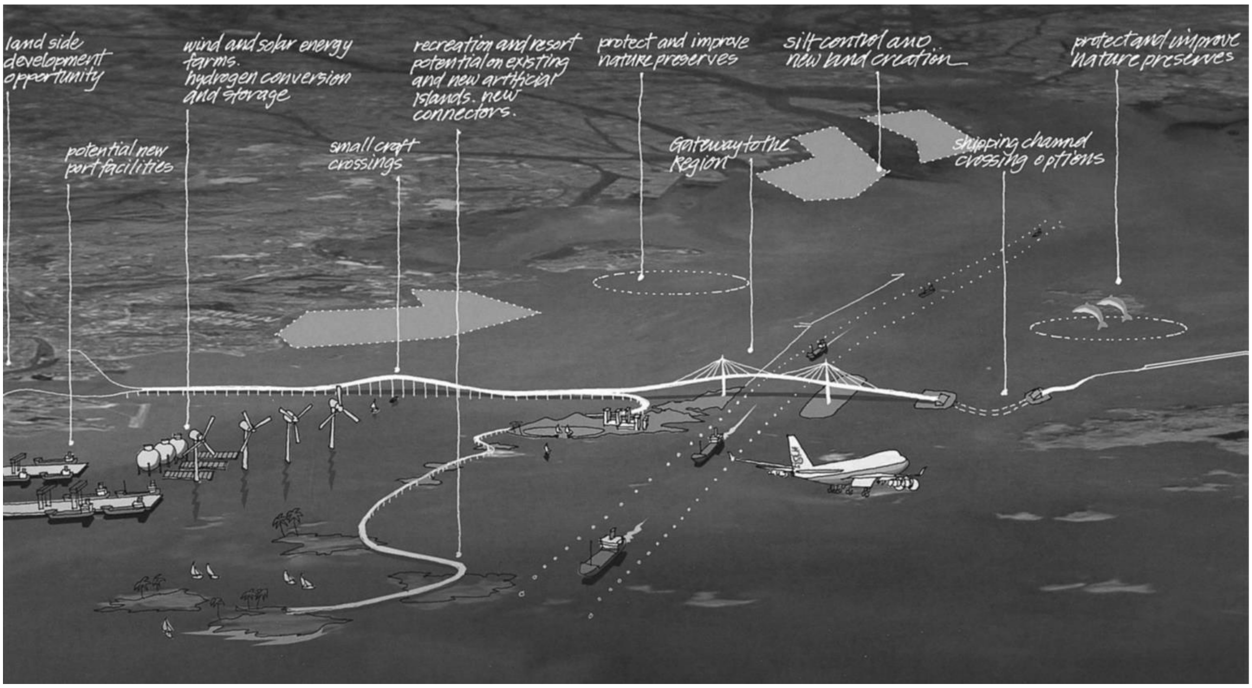
1. An interdisciplinary team will need to go far and fast in preliminary thinking about a project like this. It will not be possible to take the time to study all of the issues that arise, nor will it be necessary to go into tremendous detail at this early stage of project evaluation. Digressions on methodological issues or technical issues may divert time and resources from understanding strategic issues that could affect the public debate.

2. The private sector may realize the gross feasibility of project – so someone may push for an immediate start, and the public response may be "why not let them begin?" It is necessary to emphasize that the public should be looking for the best project, not simply a good project or a profitable project. The benefits of a project may be great enough to "really do it right".

3. Spirited discussion may quickly give a greater appreciation of options – location, size, design, related infrastructure, timing, etc.

4. A project may initially be regarded as a local project with very specific costs and benefits. As discussion progresses, a study team will gain a greater appreciation of a wider range of costs and benefits affecting regional and national as well as local concerns.

Figure 1 Schematic Representation of the Issues Related to Bridging the Pearl River Delta



Source: *Linking the Delta: Bridging the Pearl River Delta,* 2022 Foundation, Hong Kong, 2003

Case Study
Alternatives for Exporting Soybeans from Bolivia

If the right questions are asked, or if you talk to the right people, you might realize that the rationale for a proposed project has overlooked some critical factors. In this case study, the question was initially framed as a matter of filling in a gap in the Bolivian rail system that would make that rail system more competitive with Brazil's. It soon became apparent that the real completion was neither the existing Brazilian rail system nor the proposed extension of that system. Instead, the real competition came from a completely different mode of transportation.

The eastern region of Bolivia, like the adjacent portions of Brazil, includes some of the most productive agricultural lands in the world. Soybeans are one of the most profitable crops in this region, as there is worldwide demand for soy products and the South American harvest is six months offset from the more abundant harvest in the northern hemisphere. Because of a 1000-mile gap in the Bolivian rail system, soybeans have to be exported via Brazil. If this gap were filled by a new railroad, then soybeans could be hauled over the Andes to a Pacific port for export to Asia, saving thousands of miles for the ocean trip, not to mention avoiding the delay and cost of going through the Panama Canal. The idea of constructing a rail line to unite the agricultural east with the central and western portions of the country has been discussed for more than 75 years. Known as the "Interconnection", this line has been the dream of many an engineer and many a railroad president.

A transportation consulting firm conducted a preliminary study comparing the cost of moving soybeans by rail from eastern Bolivia to Brazilian ports on the Atlantic to the cost of moving via Bolivia to Chilean ports on the Pacific. The study showed that the Bolivian route would be competitive, so the government continued to explore the issue. Another consulting team was asked to visit exporters and transportation officials in both the Santa Cruz region of Bolivia and in the neighboring states of Brazil. The team updated the analysis of the prior study and confirmed that the Bolivian rail route was indeed competitive with the existing rail route to the Brazilian ports on the Atlantic. However, Brazilian rail officials described their plans for building a new rail line that would connect to a port on the Amazon, which would shorten the rail trip by more than a thousand miles with little change in the ocean shipping cost; they expected that this route would be used to export soybeans from much of the region. With this new route, it was no longer as clear that the Bolivian Interconnection would be able to attract a substantial amount of soybean traffic.

Interviews with exporters were even more discouraging, for they pointed out that most of the soybeans moved south on the Parana River to Argentina, where they were loaded onto ships for export around the world. The barge movements along the river were much cheaper than the rail movements, and the main costs of ocean shipping related to loading and unloading. The savings from having a shorter ocean trip were nowhere near enough to cover the increases in cost that would result from using rail to reach a Pacific port.

Failing to include barge transportation was a major defect in the original study. Had government officials not been so concerned with competing with Brazil's rail system, they might have recognized the need to investigate the inland waterway option. Had the consultants viewed their task as studying choices faced by exporters rather than as a study of relative costs of using different rail routes, they would quickly have realized that the barge service was superior (i.e. much cheaper) than any of the existing rail options.

In this case, the "do-nothing" option prevailed, and Bolivia did not attempt to build a railroad up the eastern slope of the Andes.

Case Study
Scenario Planning at Southern California Edison

By focusing on plausible uncertainties and postulating alternative futures, scenario planning emphasizes the unpredictability of future events and their impact on operations, sales, prices, demand, and so forth. The process of constructing and analyzing the impact of scenarios forces the planners to delve into the dynamics, the cause-and-effect relationships that determine the future. The process identifies major weaknesses as well as major opportunities that exist under different scenarios. Consequently, management can prepare contingency plans to deal with threats and take advantage of opportunities.[1]

Southern California Edison (SCE) used scenario planning to guide its investment strategy when faced with the need to expand its production capabilities. They used a three-stage process: scenario development, implications of scenarios, and development of strategies. As the first step in scenario development, they identified eight key factors that would influence their need for generating power:

- Price of fuel and purchased power
- Base case rates based upon current operating and maintenance costs
- Demand for electricity, which was assumed to be proportional to economic growth
- Changes in environmental regulations
- Open access to SCE's transmission
- Customers generating their own power
- Technical innovation (for the company and for consumer appliances)
- Population growth
- Generation shutdown

They then created an initial set of 45 scenarios based upon these eight drivers, which they clustered into groups from which they eventually selected twelve scenarios for analysis. The twelve scenarios were each defined by changes in production requirements related to the eight drivers. The scenarios were designed to span a range of production ranging from 5,000 megawatts below their base case forecast to 5,000 megawatts above. Table 1 shows how four of the strategies were defined in terms of increases or decreases in production that were related to the eight drivers. Taken together, these twelve scenarios indicated the extent to which SCE should plan for dealing with the need to increase or decrease production. SCE then identified ways that they could increase or reduce production capacity for each scenario, by using strategies such as the following:

- Capacity could be increased by 900 MW by taking power plants out of standby reserve or reduced by as much as 1500 MW by putting additional power plants into standby reserve.
- Energy purchased from other companies could be increased by as much as 2,000 MW.
- Energy management, such as peak load pricing, could be used to add 500 MW or to reduce 1050 MW of production.

This analysis revealed problems that SCE would have to deal with under some of the extremely low or extremely high demand scenarios. For example, to deal with increased power needs, SCE identified projects that could be implemented quickly so as to increase capacity, and they determined that they would need to enhance their ability for energy management.

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[1] Fred Mobasheri, Lowell H. Orren, and Fereidoon P. Sioshansi, "Scenario Planning at Southern California Edison", **Interfaces** 19:5, 1989 p. 34.

Table 1 Change in Production Requirements (in megawatts) for Selected Strategies and Scenarios

Driver	Economic Bust	Expanded Environmental Concern	Low Cost Fuel	Economic Boom
Fuel and purchased power	-1,000	-	1,000	500
Base rates	-500	-	500	500
Economic growth	-3,000	-	2,000	3,000
Environment	-	-1,500	-	-
Open Access	-	-	-	-
Self-Generation	-	-	-	-
Technical Innovation	-	-	-	500
Population Growth	-500	-500	500	500
Generation Shutdown	-	-	-	-
Total Changes from Base Case	-5,000	-2,000	4,000	5,000

Source: Mobasheri et al, 1989, p. 38.

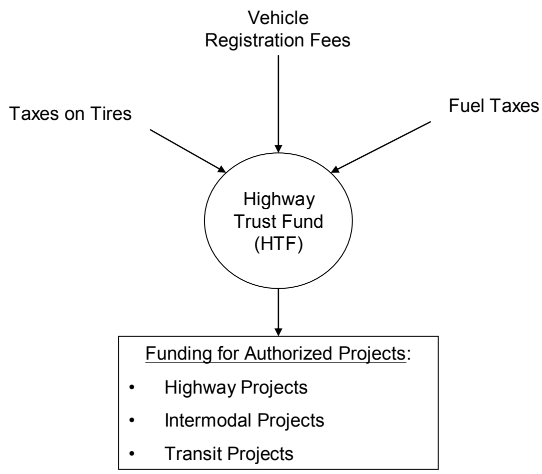
Case Study
Financing a Bridge Project

This hypothetical example explores whether or not it makes sense to consider building a bridge as a public private partnership.

Overview of Options for Financing a Bridge Project

A bridge could be built as a public project, a private project, or a public private partnership (PPP). If the bridge were built as a public project, then there would be several options for financing. The bridge could be viewed as part of the highway system, and whatever funds are used to construct highways could be used to pay for the construction of the bridge. For example, the federal or state government may have a highway trust fund (HTF)[1] that uses income from fuel taxes and registration fees to pay for authorized additions to the highway network (Figure 1). If the bridge is approved as a project that can be supported by the HTF, the design and construction of the bridge can begin. This was the basic approach used in the United States to create the Interstate Highway System and many state highways. State and city governments may also use tax revenues to support highway projects, and they can sell bonds to raise some of the funds required for construction (Figure 2).

Figure 1 Structure of a Highway Trust Fund
Money collected from various fees and taxes is used to fund authorized projects, sometimes including transit or intermodal projects as well as highway projects.

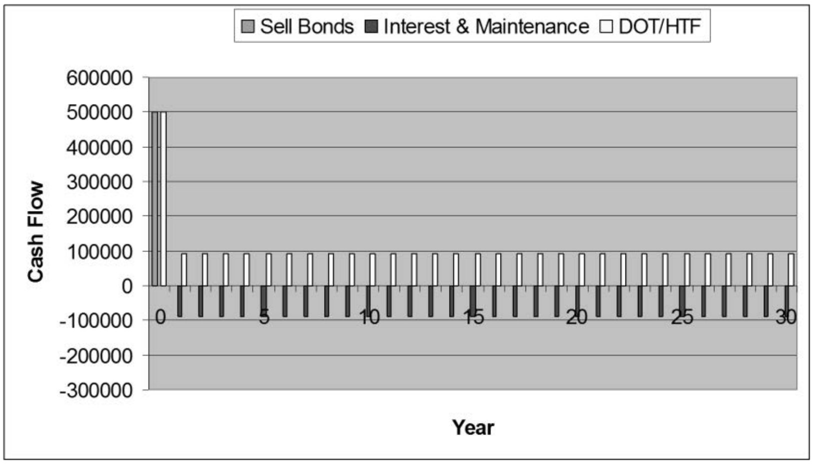


A city or state will commonly finance a bridge project using funds from the HTF or by selling bonds to cover the construction costs and using money from the state's Department of Transportation (DOT) budget to cover annual operating costs. If bonds are sold to help finance the bridge, and if there are no tolls on the bridge, then the bonds are

[1] The federal HTF was created in 1956 as a mechanism for financing the constructing the Interstate Highway System. Fees and taxes on fuel and heavy trucks provided sufficient revenue to cover the federal government's 90% of the construction costs. Subsequent legislation allowed small amounts of the fund to be diverted to transit and intermodal projects. The federal fund can only be used for construction, not for operations or maintenance, which remain state responsibilities. States have similar funds, with fuel taxes again providing the major source of revenue. For the complete history of the HTF and the Interstate Highway System, see Tom Lewis, *Divided Highways,* Penguin Books, NY, 1997.

backed by credit of the state or local government. If there are tolls, then the bonds would be backed by the expected toll payments. Once the bridge is constructed, it clearly belongs to a particular government agency and that agency or another agency is responsible for maintaining and if necessary rehabilitating the bridge. If bonds were sold to pay for the bridge, then those bonds may affect the credit rating of the city or state. If the project were funded out of tax revenues, then it may have been necessary to defer work on schools, water resource projects, or other government projects or activities. Also, some cities or states have limits on the total debt that they can incur. Borrowing to pay for the bridge therefore may limit their ability to borrow for some other purpose. Hence, there may be strong incentives to use tolls to finance the bridge.

Figure 2 Cash flows for a typical bridge project.



Some additional analysis is needed to determine whether toll financing, a state highway project or a public private partnership (PPP) is the best option for this bridge. The first question is whether or not the bridge is on a route that would qualify for funding as part of the state highway system. If not, the next question is whether or not high enough tolls can be charged to cover the costs of interest and operations. If so, then the question is whether the city should build the bridge and collect the tolls or whether the city should create a public private partnership to build and operate the bridge. The city could authorize the bridge and provide the connections to local roads, while a private company could raise funds to pay for the construction costs. The private company would then charge tolls so as to earn a return on its investment. This approach works only if the expected value of the tolls is sufficient to provide an adequate return on capital, e.g. more than enough to cover the interest due on bonds and annual operating expense. The limit on the toll would be the value that users would place upon using the bridge. The toll could be quite high for a bridge that would provide a much shorter or less congested route, but if other bridges are located nearby, then the presence or absence of tolls on those bridges would affect what can be charged on the new bridge. With this approach to building the bridge, the costs would be borne by the private company, not by any public agency, so the construction of the bridge would not affect any public budgets or capital plans. On the other hand, if the bridge is built privately, then the design and capacity of the bridge, as well as the level of tolls charged would be determined by the private company, possibly with an eye toward maximizing profits rather than maximizing public benefits. There could be intense public opposition to allowing a private company to charge what might be viewed as exorbitant tolls in order make excessive profits on an ugly bridge with limited capacity. Thus, there would likely be political pressure to retain some aspect of public control over the project.

Figure 3 Toll Booth on the West Virginia Turnpike
Most of the turnpikes in the U.S. were constructed by state governments prior to the start of the Interstate Highway Program. Tolls cover the interest and redemption costs related to the bonds sold to finance the roads and also cover the costs of maintenance and operations. Tolls can also be used to manage congestion, by charging higher rates at peak hours or by charging higher rates for an express lane. Some states have considered privatizing their toll roads as a means of capturing the value of their investments, either to finance future transport system improvements or to reduce their states' indebtedness.

Various options could be used in a PPP. One common approach is for the public agency to seek bids in which the key variables would include a) the design of the bridge, b) the tolls to be charged and c) the length of time over which the private company would operate the bridge. The bridge would be owned (or eventually be owned) by the public agency, but it would be operated for an extensive period before it was turned over to the public agency. The public role could be to retain control over the size, design, location, and purpose of the bridge; to ensure that the tolls are reasonable; to provide some financial security for the private company by providing some sort of minimum annual payment if traffic volumes do not rise as expected; or to provide assurance that a competitive project would not be built within some specified period of time.

Let's examine the various financing options using a hypothetical bridge project. Suppose that a new bridge has been proposed that would reduce the travel time and cost between two rapidly growing regions in the rural portion of a state. The bridge, which is strongly supported by local officials, would create a route that would save each user an average of 10 miles and 15 minutes. The bridge is expected to cost between $40 and $60 million to construct, and annual maintenance and operating costs are expected to be $4 to $5 million. There are currently 10,000 vehicles per day that use the route, and a preliminary study indicates that nearly all of this traffic would use the new bridge. About 80% of the vehicles on this route are automobiles, while nearly all of the rest are trucks. We will consider three options, namely structuring the project as a routine state highway project, as a private toll bridge, or as a public/private initiative.

Can the Bridge be Justified as a State Project?

Local officials would like naturally prefer the option in which the state pays for the bridge and does not charge a toll, as this would result in the maximum benefits for local citizens and companies. They would also like the bridge to be constructed as soon as possible, preferably within the next two to five years. The big question is whether or not this bridge project can be justified as part of the state's transportation investment plan.

To answer this question, it is necessary to consider the state's transportation budget and the nature of other projects competing for state funds. The state has a prioritized list of transportation projects based upon a formula that recognizes the benefits of reducing congestion, improving safety, reducing travel times, and promoting economic development. For this example, assume that it is apparent that the proposed bridge would not have a very high priority. There are many projects involving bridges and road rehabilitation involving much more heavily traveled routes in more densely populated areas of the state, while the existing route, though long, has very few accidents and essentially no congestion. In short, this is a low priority bridge, and there is no immediate way to dramatize the need for it. Moreover, the state's highway trust fund is substantially underfunded, primarily because fuel taxes have not been increased for nearly 20 years. The trust fund can barely provide enough funds for high priority projects, and medium priority projects have been set back ten or more years in the state's investment plan. In short, local officials cannot expect to have the state pay for the proposed new bridge.

Could a Private Bridge Project be Financed with Tolls?

Would it be possible for a private company to build the bridge? If so, would that be a good idea for the region? The economic value of the bridge is the time and cost saved by those who use the bridge to shorten their travel distances plus additional benefits related to economic development that is likely to result from the increase in mobility provided by the new bridge.

In this example, assume that the major economic benefit comes from a reduction in travel expense for those that use the new bridge. The state DOT estimates the marginal cost per mile for driving an automobile to be $0.20, taking into consideration the cost of fuel and the wear and tear on the vehicle. The marginal cost per mile for driving a truck is on the order of $0.50. The average value of the time saved is on the order of $10/hour for automobile passengers and $20/hour for trucks.

Would a private company be able to finance the bridge by selling bonds backed by toll revenues? The first step is to estimate the annual revenue that must be raised by the tolls. If the bridge is financed by selling corporate bonds, the interest rate would have to be about 8%. The interest costs would therefore be 8% of the construction cost, or $3 to $5 million.[2] The total annual cost, including maintenance and operations as well as interest, would therefore be $8 to $10 million.

The next step is to estimate the potential annual revenue. The toll can be no higher than the economic benefit of using the bridge. Using the DOT cost numbers, the average benefits per user can be estimated:

Auto benefits = 10 miles ($0.20/mile) + 0.25 hours ($10/hour) = $4.50
Truck benefits = 10 miles ($0.50/mile) + 0.25 hours ($20/hour) = $10
Weighted average benefits per vehicle = 0.8 ($4.50) + 0.2 ($10) = $5.60

If 10,000 vehicles used the bridge per day, the annual economic benefits would be as follows:

Annual benefits = $5.60/veh. (10,000 veh./day) (365 days/yr) = $20 million per year.

In other words, the annual economic benefits appear to be at least double the annual costs for interest and operations, even if the bridge costs are at the high end of what is anticipated. A toll of $3 for automobiles and $6 for trucks would be sufficient to cover annual costs. Moreover, since the regions served by the bridge are rapidly growing, traffic volumes and toll revenues would be expected to rise. Thus, it does appear to be feasible for a private company to build the bridge using money raised by selling bonds and paying the interest on the bonds with tolls that users would be willing to pay.

Should the Bridge Be Built as a Public Private Partnership?

The public might well object to the prospect of a private company building the cheapest possible bridge and charging the highest possible tolls. The analysis has shown that a toll of $3 per car and $6 per truck would be more than sufficient to cover the 8% interest rate that the private company would pay on its bonds. However, the same analysis showed that the toll could be nearly 50% higher and still attract most of the traffic. If the bridge is as critical as the local officials believe, and if the region continues to grow as expected, then traffic volume – and toll revenues – would

[2] If the construction cost is at the low end of the estimates, then the annual interest will be 8% of $40 million; at the high end of the estimates, the interest would b 8% of 60 million. These are all estimates, so all that can be said is that the interest payments are likely to be $3 to $5 million per year.

be expected to increase substantially over the life of the bridge. Might it be better to structure the project as a public/private partnership?

The logic for public involvement is that interest costs could be lowered and that tolls could be controlled. A regional authority could be created that would approve the design for the bridge and own the bridge, and this authority could seek a partner or partners to construct and operate the bridge. With public backing, it would be possible to get lower interest rates by selling tax-free municipal bonds to fund the project. Even if the regional authority were unwilling or unable to sell bonds to finance the project, they could still seek bids for constructing and operating the bridge. They could also stipulate that the bridge (and the toll revenues) would revert to the regional authority after a period of twenty or more years.

In fact, major bridges are commonly funded by tolls. So long as there is a substantial amount of potential traffic that will enjoy considerable time savings, tolls can be used to pay the interest on the bonds issued to finance the project. Figure 1 shows the entrance to the tunnel portion of the Chesapeake Bay Bridge/Tunnel. This project drastically improved connectivity within the State of Virginia and also provided a much shorter route for travel up and down the East Coast.

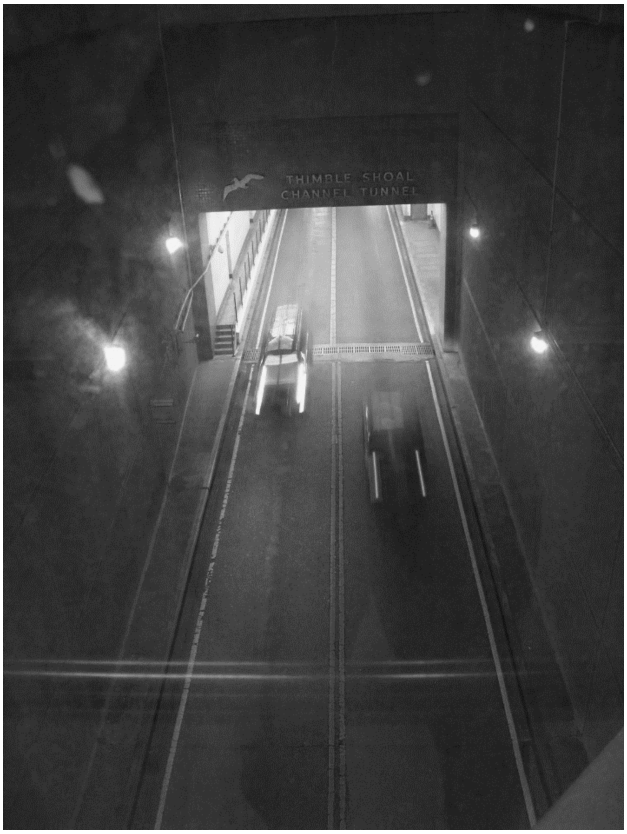


Figure 1 The Chesapeake Bay Bridge/Tunnel
This 20-mile bridge/tunnel was built between 1960 and 1964 in order to link the Norfolk region with the Eastern Shore of Virginia. The tunnel portions of the project ensure that Chesapeake Bay will always remain open to shipping and to the U.S. Navy; islands created for the entrances to the tunnels are in themselves a tourist attraction.

The bridge/tunnel not only provides a link between two areas of the state, it provides a much shorter and less congested through route than Interstate 95 for much travel along the East Coast. Because the bridge saves so much time compared to a ferry, and because the route is much shorter and less congested the I95 route, travelers are willing to pay the substantial tolls of up to $15 for automobiles and $26 for trucks. A second two-lane bridge was added in 1999 in order to provide extra capacity and avoid congestion. Both bridges were financed by tolls, and no local, state, or federal tax dollars were used.

Case Study
Public Incentives for Low-Income Housing

Public and private interests may come together to promote multiple objectives by allowing denser development in a suburban setting. Re-zoning land for denser development can offer great opportunities for developers; requiring the new developments to serve social purposes, such as housing for families with low-income, may be the grounds for a public private partnership.

Suppose that a developer is interested in constructing apartment houses in a suburban town where zoning currently allows only single-family housing on one-acre lots. The developer has plans for constructing three buildings with ten apartments each on a five-acre site. The expected cost per unit is \$150,000 and the developer plans to lease the units for \$2,500/month. Operating expenses are expected to be \$500/month per unit. The annual net income is therefore:

Annual net income = 10 units (\$2,000 /month/unit) (12 months/year)

= \$240,000 per year

Since each ten-unit building is expected to cost \$1.5 million to construct, the expected ROI is expected to be \$240,000/\$1.5 million, or 16%. The developer's minimum acceptable rate of return (MARR) is 12%, so this is a very attractive proposition. However, unless the zoning is changed, the five-acre site will only be able to be used for five single-family houses. Without the zoning change, the developer would have to sell the recently acquired site and seek development rights elsewhere.

The town is interested in creating housing that will be suitable for low- and middle-income families. They thought that it might be possible for the town to build low-income housing, which would be made available to town employees at a maximum rent of \$1000 per month. They found that the construction costs for a five-unit building would be \$160,000 per unit, with monthly operating costs of \$600 per unit. The net rent per month would therefore be just \$400. The town could sell bonds with an interest rate of 4%, so that the annual interest cost per unit would be 4% (\$160,000) = \$6,400. The net rent of \$400 per month or \$4,800 per year would be insufficient to cover these interest payments. If the town went this route, they would have to include an additional \$6,400 - \$4,800 = \$1,600 per unit in the town's budget, which they would prefer not to do. The town therefore approached the developer about the possibility of allocating some of the units in the proposed apartments to low-income residents whose rent would be set at \$1,000 per month.

The first question is whether or not there is some basis for a partnership. To answer this, we need to determine the maximum reduction in rent that the developer could accept while still earning an acceptable return on the project. To achieve a return of 12%, the developer needs an annual operating profit of \$180,000 (12% of the \$1.5 million investment), which is \$60,000 less than the expected lease payments of \$240,000 per year. Reducing the rent from the market rate of \$2,500 per month to the desired rate of \$1,000 per month for a low-income resident would cause a loss of revenue of \$1,500/month or \$18,000/year for each unit. Thus, even if the developer had to make three units available to town employees at the lower rent, he would still have an acceptable MARR:

ROI with 3 low-income units = (\$240,000 – 3 x \$18,000)/\$1.5 million = 12.4%

If the developed is forced to decide between abandoning the project and accepting a project in which three units are reserved for low-income families paying lower rents, then the developer would likely accept the deal. Of course, the developer would be likely to say "if you provide a subsidy of \$1,500 per month per unit (\$18,000 per year), you could rent as many as you like."

The town would probably consider $1,600 per year as the maximum subsidy that they would consider, as they could build their own complex if they were willing to provide that level of subsidy. Thus they would be unwilling to provide anything close to the desired subsidy.

On the other hand, they could perhaps offer something else. Suppose the state had approved legislation aimed at promoting the development of low-income housing by allowing the state to guarantee the interest on loans associated with constructing housing in which at least 25% of the units were reserved for qualifying low-income families. Under this legislation, the interest rate on the developer's loans would drop by 2% if the development qualified. If the developer had a loan of $1.5 million, a 2% reduction in the interest rate would be worth more than $30,000 per year. This would be equivalent to $10,000 per unit if three units were reserved for low-income families.

Is this enough to close the deal? Maybe and maybe not. It depends upon how badly the developer wants to proceed and how aggressive the town is willing to be in considering the re-zoning application. It is conceivable that some residents in the town will prefer not to attract low-income families – and it is conceivable that others will be very supportive of initiatives that allow young families and public employees to live in the town. Another step that could be taken would be to allow the developer to add a couple of more units to each building, thereby making the overall development more attractive.

Case Study
The Sheffield Flyover, Kansas City, Missouri[1]

This project illustrates how public agencies can work with the private sector to expand capacity and improve the performance of the local transportation system, with benefits to the region and the nation as well. This project, which had substantial public as well as private benefits, only became feasible when public agencies and the railroads figured out how to work together and share the costs.

Overview

The Sheffield Flyover increased the capacity and improved the performance of a major bottleneck in the rail network in and around Kansas City. At-grade crossings of high-density rail routes had not only led to train backups, but also caused extensive delays to highway traffic when trains blocked local streets. An innovative public private partnership helped secure funding for and ensure the successful implementation of the flyover. Because of the success of the Sheffield Flyover, the railroads and public agencies decided to build a second major flyover in Kansas City in order to secure similar benefits.

Project Description[2]

The project addressed a key bottleneck in the national rail system where the Burlington Northern Santa Fe (BNSF) main line crossed the Union Pacific (UP) and Kansas City Southern (KCS) main lines. With 100 to 120 trains operating on the BNSF, 60 to 80 on the UP and KCS, and another 40 to 60 local trains operating in the area, this was described as the "third busiest railroad intersection in the country". Trains were inevitably delayed as dispatchers worked to route them through the bottleneck; the delayed trains blocked highway intersections for a mile or more. The resulting delays were especially difficult for trucks seeking to enter or exit a major industrial area hemmed in between the main lines.

By constructing a flyover, it was possible to eliminate rail and highway delays associated with train interference at the crossovers. The project covered nearly three route-miles almost entirely constructed on the Kansas City Terminal Railroad's right-of-way; it included a main bridge of 6,740 feet and two other bridges of 890 and 150 feet. By double-tracking the flyover and keeping the existing tracks, it was possible to greatly increase the capacity of the intersection, thereby improving the flow of trains moving through Kansas City and also providing better service to local rail customers. From the public's perspective, the most visible benefit was expected to be a reduction in delays at grade crossings. Transystems, a consulting firm involved in evaluating the project, estimated that an average of 530 vehicle-hours would be saved daily for cars and trucks by elimination of grade crossings, based upon the train volume, the average time that each train blocked a crossing, and the 4,500 daily highway vehicle movements through the area. At $14/hour, this was estimated to amount to a savings of $1.85 million annually. In addition, with fewer trains and vehicles delayed in the area, emissions were expected to be sharply reduced.

Transystems did not provide details on the railway benefits, but indicated they would be approximately three times as great as the public benefits. This is borne out by a quick assessment of the benefits from reduced train delay. If 150-180 trains per day each saved 20 minutes in moving through this region (as estimated by Transystems), that would be a savings of more than 60 hours of train delay per day or 20,000 per year. The cost per train-hour is commonly estimated to be on the order of $250/hour based upon the hourly cost of equipment ownership plus the opportunity

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[1] This case study is based upon material prepared by C. D. Martland for the National Cooperative Highway Research Program as an example of public/private partnerships. The case study was part of the research conducted under research project NCHRP 8-42 "Rail Freight Solutions to Highway Congestion."

[2] Transystems Corporation, "Kansas City Terminal Railway Flyover Project: A Public/Private Cooperative Success, Presentation" to **Financing Freight Transportation Improvements**, FHWA Conference, St. Louis, MO, April 29, 2001

cost associated with the loads themselves. Hence the delay cost of an average 20-minute delay to these trains would exceed $5 million per year.

The project cost was $75 million. Raising the capital was a stumbling block for the railroads, even though they were willing to pay for the project on a continuing basis. Another problem was that construction would increase the assessed value of the property and therefore the property tax owed by the railroads. Various public agencies were interested in providing financial support, but there were barriers to using public funds. At one point, it appeared that a Federal Highway Administration (FHWA) loan would be approved to finance 25% of the project, based upon the public's share of the project benefits. This loan possibility fell through when trucking interests objected to the use of highway trust money for rail projects. State agencies were interested, but were prohibited from investing in a private sector project.

The financing problem was resolved by creating a "Transportation Corporation," a quasi-governmental entity that can be created under Missouri law that can receive highway funds. A "T-CORP" can issue 20-year, state tax exempt bonds to fund transport projects, and it receives real estate tax abatements. A "T-CORP" is represented jointly by the project owner and the Missouri Highway Department"; the T-CORP owns the land and the project until the loans are paid off, at which point the land goes back to the previous owners. The net result for the Sheffield Flyover was that the T-CORP issued the bonds, the US DOT provided a letter of credit, and the railroads agreed to repay the loans. In addition to benefiting from low interest rates, the corporation enjoyed a property tax abatement worth $1.4 million per year (estimated by Transystem as being nearly 20% of the annual amortization costs).

The project required a few other elements of cooperation. The project was supported by the Heartland Freight Coalition and the Greater Kansas City Chamber of Commerce, as well as the Missouri Department of Transportation, Federal Highway Administration (FHWA), and the railroads. Some public land was needed for the flyover, and a land swap was arranged with the City. While the project was underway, work was done to modernize or coordinate 14 different utilities serving this industrial area. Also, a portion of one of the city streets had to be reconstructed and temporarily closed to enable completion of the flyover.

Motivation

Kansas City is the second-largest rail freight hub in the country after Chicago. It is served by four Class I railroads: (Burlington Northern Santa Fe (BNSF), Union Pacific (UP), Norfolk Southern (NS) and Kansas City Southern (KCS), while the Gateway Western provides an independent route that reaches CSX in St. Louis. The Kansas City Terminal Railroad provides local switching services, and various short line and switching railroads serve the area. The metropolitan area has an intricate network of classification yards, industrial support yards, and through tracks. A major problem within the region is that major rail routes intersect in Kansas City, resulting in extensive delays to both trains and highway vehicles.

The Mid-America Regional Council documented the importance of rail to the region.[3] Rail handled just over half of the freight tonnage moving through Kansas City. Over 80% of the rail freight was moving through the area, and this traffic amounted to 150 million tons in 2000. Much of this traffic was intermodal (i.e. containers or trailers that are transferred by truck between customers and intermodal terminals and moved by rail between the intermodal terminals). The BNSF's route from Los Angeles to Chicago, which handles 1.6 million containers and trailers annually, goes right through Kansas City. Another 23 million rail tons was received by Kansas City industries, while about 11 million tons were shipped out by Kansas City shippers. Rail's market share varies greatly with the type of movement. Rail accounted for approximately two thirds of the freight moving into or though the region; truck accounted for all of the intra-regional freight and more than three quarters of the outbound freight. The rail share vs. truck was growing for through traffic, stable for traffic inbound to the region, and declining for outbound traffic.

[3] Mid-America Regional Council, "Transportation Outlook 2030, Metropolitan Kansas City's Long-Range Transportation Plan", Mid-America Regional Council, October 2002

During the 1990's, it became increasingly evident that various national trends in rail freight traffic were disrupting both rail and highway traffic in the city. Rationalization of the network was concentrating more traffic on fewer routes, leading to congestion and interference within the rail network, as well as increasing delays to highway traffic. Trains waiting for authorization to proceed through an intersection often blocked automobiles and trucks at grade crossings, frequently for 20 minutes or longer. Mergers, traffic growth, and shifts in freight traffic patterns required greater capacity along key rail routes within the city, but the bottlenecks where key routes intersected threatened to limit growth of rail traffic.

The project therefore was seen to have both local and national significance. Grade crossings and local air quality were the obvious benefits for the local area. However, the movement of 1.6 million trailers and containers by train rather than by highway was recognized as much more than a local benefit, since these shipments might otherwise be moving on the highways not just through Kansas City, but also through many other cities throughout the country. Expanding the capacity of such an important rail hub was also of major significance for the national rail system. The 150 million tons of freight moving through the rail hub represented at least seven million truck shipments, including the intermodal trailers and containers mentioned already. This is a good illustration of a network-level investment where important improvements in system performance help retain existing customers and attract new customers.

Results

The project achieved its goals. Following the opening of the new facility in 2000, travel times for trains dropped from 40 to about 15 minutes.[4] This improvement in train efficiency translated directly into the hoped-for reduction in grade crossing delays and air quality. The institutional structure also worked well enough to be expanded. In February, 2002, BNSF announced that a second major flyover would be constructed to provide grade separation at the intersection of two of their main routes and improve access to Argentine Yard, their major freight facility in the region.[5] (BNSF, 2/15/02). The "Argentine Flyover", which would cost about $60 million, was initiated using the same institutional arrangements as the Sheffield Flyover.

The project received broad recognition as an outstanding example of public/private cooperation. The Intermodal Advisory Task Force of the Chicago Area Transportation Study identified this project as one of the best examples of "holistic" planning "involving major transportation industries, the political decision-makers, plus the industries (shippers and receivers, essentially) that stood to benefit."[6] Rawlings noted the key roles played by the Chamber of Commerce and the Mid-America Regional Council, who funded preliminary freight studies and were able to focus interest on and achieve a consensus for the flyover and a few other critical projects.

Lessons Learned

Table 1 summarizes the key elements of this project. In this case, the train volumes were so high and the benefits so large that it was easy for local parties to agree that the benefits justified the costs of the project. At intersections of busy rail lines, trains back up and clearly block the local highway network. These local costs were easily identifiable and large enough to justify public participation, even though the national significance of the project is what motivated FHWA's interest. The benefits were equally clear to the railroads, as were the costs to operations if action were not taken.

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[4] Cookson, Brian, "Railway putting flyover on track", The Business Journal of Kansas City - November 5, 2001 (from the November 1, 2001 print edition).
[5] BNSF News Release, "Second Flyover Bridge to Streamline Rail Traffic Through Kansas City," Kansas City, Kansas, February 15, 2002.
[6] Rawlings, Gerald, comments posted on "National Dialogue on Freight" Website (referenced March 14, 2003).

This project provides various lessons for promoting public/private partnerships that seek to enhance a system in order to achieve both local and national benefits:

- The involvement and support of the local interests is essential.
- The willingness of the various partners to work together and to negotiate ways to share the costs is essential.
- Federal, state and local cooperation can provide innovative financing mechanism and enable a complex project to be completed quickly.
- Environmental benefits may provide part of the story in support of the project, but the financing may need to be based upon a clear understanding that the system improvements – both local and national - translate directly into enough cost savings to justify the project.
- The national scope of the project may add to the story and motivate federal involvement, but it may not directly affect the local assessment of the project. In other locations, where the local effects are not so evident, it may be necessary to make a stronger case for the indirect and national benefits in order to secure local support and a broader base of funding.
- Once a coalition is formed to identify, finance, and implement projects that fulfill clear needs, then that coalition can quickly move on to additional projects.

Table 1 Key Elements of the Kansas City Flyover Project

Reason for PPP	Project justified by the combination of public and private benefits, and it required innovative cooperative relationships for implementation.
What was done	Rail lines and some public property were conveyed to a special public agency that constructed flyovers that eliminated some of the main at-grade rail-rail and rail-highway crossings in Kansas City.
Benefits	Financial: the railroads reduced their operating costs. Economic: reduction in delays to highway traffic at grade crossings.
Financing	Low-interest bonds and property tax abatement: the project was financed with low-interest tax-fee bonds, which would be paid back by the railroads in proportion to their use of the facility. By transferring the land to the city, the railroads would not have to pay property tax.
Major risks	1. Would construction costs be higher than predicted? 2. Would traffic volumes be high enough to produce enough revenue to cover the annualized costs of the project? This risk was thought to be minimal, as this region was the second-busiest rail hub in the country.

Case Study
Skyscrapers and Building Booms

You and your directors were well advised in the choice of your symbol. For a tower, with its light and its belfry, has always been a source of inspiration. ... Thus your Tower partakes of the character of the ancient towers of refuge and defense ... Your high tower should, therefore, be a symbol of God to you and others, standing out boldly and erect as a plea for righteousness and purity in business corporations, and as a monumental protest against the exploitation of the poor.[1]

The technologies necessary to construct buildings of almost unlimited height became available in the mid- to late-19th century. In locations where land values were high, the potential benefits of building a skyscraper were immediately obvious. While the visceral appeal of towers may have appealed to certain visionaries, overly powerful executives and politicians, the ability to replace a 5-story building with a 25-story building excited the financial instincts of developers and real estate agents. Whether buildings were designed for office space or for apartments, the ability to rent far more building space on the same site was a prospect too enticing to resist.

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Table 1 Technological Innovations Required for the Construction of Skyscrapers

Steel frames	1848	James Bogardus demonstrates how to use cast-iron posts and beams to support a building without relying upon the walls, but height is limited to 7 or 8 stories.
	1880	Using steel rather cast-iron allows framing much higher buildings because steel is more flexible, stronger, and can be joined with rivets rather than nuts and bolts. Leroy Buffington shows how tall steel-framed buildings could be built.
	1883	William Le Baron Jenny uses Buffington's method in design for the first skyscraper, the Home Insurance Company Building in Chicago, which was built using a steel frame rather than using steel to reinforce thick masonry walls.
Elevator	1853	Graves Otis demonstrates an elevator at the Crystal Palace in London.
	1870	Equitable Building in NYC is first building to install an elevator.
	1889	Otis installs the first electric elevator.
Utilities		Water for fire protection and sanitation.
		Electricity for elevators and lighting.
Fire protection		Building codes call for fire-retardant materials, fire escapes, sprinkler systems, inspections and fire drills.
Zoning		Zoning is required to deal with effect of buildings on wind currents and sunlight.

Source of information: John Tauranac, **The Empire State Building**, St. Martin's Griffin, NY, 1995

The pace at which skyscrapers were erected in New York City was astonishing (Tauranac, pp. 41-42). In the 1890s, several 20-30 story buildings were constructed in the city. By 1929, there were 188 that were more than 20 stories tall and nearly 2,500 that were more than 10 stories tall. In 1899, the 29-story Park Row Building was the tallest in the world; the world record was broken three more times in the next fourteen years in Manhattan, capped in 1913 by the 55-story, 787-foot high Woolworth building. During the 1920s, the Chrysler Building, at 1,048 feet held the record for a while until it was surpassed by the Empire State Building, which had 102 stories and was more than 1,250 feet tall.

This incredible construction boom in Manhattan was fueled by the fact that skyscrapers allowed many more people and businesses to crowd into an area with some of the highest property values in the world. The new technology made it possible to house an order of magnitude more people than could previously be housed on a site. Once developers realized the profits that could be made by rebuilding the city to a taller standard, the proposals and construction efforts

[1] This bit of hyperbole was addressed to Met Life stockholders in 1915 according to John Tauranac, **The Empire State Building**, St. Martin's Griffin, NY, 1995 p. 38. The president of Met Life was apparently more concerned with his pocketbook than with his view, as he is reported to have responded by saying "the tenants will foot the bill."

multiplied – even after vacancy rates started to increase in 1926 and a report to President Coolidge concluded that the country was overbuilt. According to Tauranac:

> *Developers had been desperate to develop, but by 1927 they were desperate to rent, to fill their vacancies, especially in apartment houses where the problem was critical. ... Realtors recognized that the profession could not view the extremely heavy construction program without apprehension of a glut on the market. (p. 83)*

Despite the slump and the dire warning, in both 1928 and 1929, developers filed plans for more than 700 new buildings in New York City. And some of these were quite spectacular plans. The planning for the Empire State Building and for Rockefeller Center were both initiated in this ambiguous period, still at the height of the construction boom, but just before the bottom was about to fall out of not just the New York City real estate market, but out of the worldwide economy.

The pace of construction seen in New York City in the 1920s was later replicated in many other locations around the world, notably Hong Kong, Tokyo, Shanghai and Dubai. Unfortunately, the instincts that cause developers to begin bigger and better projects are also perhaps too powerful to resist, even in the face of contrary economic evidence. The real estate bubble that burst in 2008 was linked to the same kinds of "irrational exuberance" and shaky financial dealings that led to the burst of the bubble in New York City in 1929.

Once a real estate bubble bursts, it may be years before development resumes. In the United States and elsewhere, construction of skyscrapers stalled because of the depression and World War II. Only after the war was it possible to resume construction of skyscrapers. As in the earlier period, technological and economic forces shaped what was built (see text box).

I began my career in structural engineering in 1947 and was in responsible charge of structural design of many notable high rise buildings including two of the world's highest over the next 40 years. I can attest to this period as one of great technological change in building design. Allowable stresses were increased by about a third and new high strength steel was developed and more precise methods of computation with computers were used to solve structural problems with speed and accuracy. Architects were anxious to express new concepts of modern design and postmodern design. The light aluminum and glass exterior curtain wall was developed and the "glass box" building was born. "Less is more" was a popular theme. Thus we had as the state of the art light-weight steel frames with glass and metal curtain walls. The new designs provided for large column free space around the central core of the buildings. The tube design was developed providing long span truss floor systems between closely spaced exterior wall columns and a grid of columns in the building core which housed elevators, stairways, mechanical shafts and wash rooms. Horizontal mechanical systems ran parallel and through the open spaces in the trusses and the structural steel was fireproofed with sprayed on asbestos cement material. After asbestos became a dirty word, other cementatious spray-on material was developed. …

Money was the primary mechanism which drove these changes. We had to build economically to offset the increasing costs of both labor and materials. Cost saving was the name of the game and engineers were notable by their ability to carry out the ever-changing design concepts of the architects with as little tonnage of structural steel as possible. For example, in the pre-World War II era, buildings in the 25 to 50 story range had steel in the order of 20 to 40 pounds per square foot. The post War buildings in the 40 to 100 story ranges had steel weights in the order of 30 pounds per square foot. There were no catastrophic failures of these structures from fire, impact or explosions until 9/11.

What we do next involves the answers to many questions and numerous decisions by participants in the design and construction process, government and concerned public. Certainly examination of fireproofing systems and structural details is a high priority, including where possible the retrofitting of existing structures. Modification of zoning ordinances limiting height and location of high buildings and changes in building codes relative to fire, explosion, and impact safety should be considered. All this involves not only technical but also political and cultural considerations. 9/11, while a terrible tragedy, should serve as a wake-up signal for a more secure building environment in this new era of terrorist war.

Perhaps the day of megastructures in the United States is and should be over for many reasons other than safety. Concentration of thousands of people in a single structure has serious infrastructure effects on transportation systems and the environment. Time is wasted and people suffer from over-stress as they rush like ants each working day into their workplace often from homes hours away. I, having been there, seen it and done it, think there are better answers to housing the core operations of commerce than trying to make megastructures safe, efficient and healthy workplaces.

E. Alfred Picardi, P.E., ASCE, May 5, 2002

Case Study
Evolution of the U.S. Rail System

The railroads have experienced what is likely a typical life cycle for infrastructure–based systems, from revolutionary to dominant to mature to declining to decommissioning. The rail industry's evolution over a period of nearly 200 years therefore provides insights into the types of problems that are encountered – or are likely to be encountered – by other infrastructure-based systems.

Overview

In the mid-19th century, the rail industry in the United States consisted of hundreds of tiny companies. Over a century and a half, these companies slowly consolidated into today's coordinated system that is dominated by four mega-carriers. Regulation and government support, initially required to avoid overdevelopment and monopolistic excess, eventually was required to help the industry reduce its network, recover from bankruptcies, and abandon large segments of business that were better served by other modes of transportation. Today, while railroads clearly have advantages over highway and airline competitors in terms of fuel efficiency and emissions, these advantages do not necessarily mean that railroads will capture more traffic. Technological advances have been critical in allowing the railroads to remain competitive – and even dominant – in some markets. Understanding where the industry retains clear advantages has allowed the railroads to segment their markets and focus on the most promising areas: intermodal traffic and bulk traffic. Effective public policy and continuing public support may be needed to sustain the rail system, especially for passenger transportation.

Introduction of Railroads in the Early 19th Century[1]

The introduction of railroads provided an incredible improvement in mobility and a dramatic reduction in the cost of moving freight. Cheap transportation plus the rapid advances of the industrial revolution spurred economic growth in the early 19th century. In the US, railroads were instrumental in opening up vast areas for development, both in terms of making land available for farmers and ranchers and providing access to new hotels in prime locations for rich tourists.

> *"The steam engine, the railroad locomotive, the transatlantic steamship, the telegraph, and the camera together virtually completed the conquest of nature by the go-ahead age. What followed were in effect refinements. ... Even the increasingly anticipated conquest of the air would, in essence, be no more than an added convenience. Its effect was simply to turn days into hours. It was the shortening of months into days by the railroads that was the basic revolution in transportation."*
>
> Page Smith, **The Nation Comes of Ages, A People's History of the Ante-Bellum Years**, p. 819

State and local governments at first tried to hold off the railroads, as they wanted to protect their investments in canals. Over time, the legal impediments to railroad building were struck down by courts or repealed by state legislatures, and by the middle of the 19th century, the railroads had an irresistible momentum. Small lines constantly consolidated in an effort to increase their access to capital and improve their service. New lines were established, and as soon as they proved themselves (or went bankrupt) they were taken up by larger lines and incorporated into a "system." Boston entrepreneurs, who had no serious opportunities for building canals, financed railroads to compete with New York City's advantageous Erie Canal route to the Northwest Territories. By 1850, Boston had links as far as Ohio and throughout New England. Three thousand miles of rail line were built for $70 million, and it was profitable.

[1] The history of the rail industry is well-documented. The facts in this sub-section were obtained from Page Smith, **The Nation Comes of Ages, A People's History of the Ante-Bellum Years**, pp. 271-277.

The emphasis quickly shifted from trying to prevent to trying to promote railroad development, especially in the Mississippi Valley region, where vast expanses of lands were unsold and unsettled because of their distance from markets. Illinois gave the Central Illinois RR 2.6 million acres of land to help finance construction, because costs had run $10 million over budget. This land was initially worth $0.16 per acre (i.e. about $430 thousand). Five years later, it was worth $10/acre; 10 years after that it was worth $30 an acre and a total of $78 million total. It was possible to get mortgages on the land in order to finance the construction of the railroads.

General economic trends were at times driven by and at times disastrous for the railroads. Construction of new lines led to a surge in demand for timber, iron, and coal. General cycles of boom and bust rapidly followed one upon the other. In the latter part of the 19th century, two thirds of the years were severe recessions or depressions. Competition among railroads was fierce, and bankruptcies were common. Potential problems such as air pollution from the coal-burning locomotives or the destruction of pristine areas and the division of cities did not impede the progress of the railroads.

Problems Emerge: Accidents, Greed, and Corruption

Railroading was a dangerous occupation, as there were many injuries resulting from collisions, derailments, and mistakes in switching cars in yards. Over time, improvements in brakes, in coupling systems, in signaling and communications, in track materials and vehicle design all contributed to dramatic reductions in the risks associated with rail operations.

Rail lines that were built to open up new regions to development could not be justified in terms of the revenues that would be received from operations. Before the railroad was built, there was little or no development, and until there was development, there would be little or no traffic. For this reason, government funds, loans, guarantees of railway bonds and land grants were used to finance the many lines in the Midwest and also the first transcontinental rail line. The government investment was justified by the potential social and economic benefits of development and, especially in the case of the transcontinental railroad, the strategic need to link California and with the rest of the country. The financial logic was that the railroad company could use the loans, mortgage the land or sell the bonds to obtain the cash required to build the rail line. Once the rail line was built, the railroad could repay the loans from land sales, operating profits, or by carrying government officials and freight at a discount. After completion of the railroad, although the government had given away large quantities of land, the remaining land was far more valuable.

The railroads that built the transcontinental railroad received land valued at $392 million as of 1880, after the railroad was built. The government's land alongside the rail route had presumably appreciated by nearly that much. The railroads had been allowed to issue government-back bonds with a face-value of $63 million, and they paid back that amount plus $105 million in interest. Thus, the government's investment in the venture turned out to be very profitable.[2]

Unfortunately, rapid expansion of the rail network and access to vast amounts of public money led to various types of fraud: misuse of the funds intended for rail construction, construction of rail lines to too high or low a standard, and construction of very expensive lines along questionable routes. In developing the railroads in the northeast, the profitability of railroads attracted unscrupulous investors and politicians eager to capture their share of the bonanza. Deals involving railroad barons such as the Goulds and politicians such as the Tweeds in New York City were infamous, as were the battles and stock manipulations of rival financiers. As the rail network moved into the west, the need for public support was much greater than it had been in the east. And the opportunity for corruption was much greater.

The greatest scandal of the scandalous Grant administration (1869-1977) involved the construction of the transcontinental railroad. The Union Pacific and the Western Pacific railroads received construction grants from the US government plus land grants along the right-of-way to help finance the construction of the first transcontinental

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[2] Ambrose, **Nothing Like It in the World**, p. 377

railroad. They were able to mortgage the land prior to construction based upon the value of the land after the construction in order to raise capital for construction. The UP owners did this through a French bank, Credit Mobilier, which they controlled. The bank declared as dividends the great majority of the funds deposited by the UP owners, who in effect defrauded the railroad and the government. Many US officials, including the Vice President, were implicated in the scandal.

Another type of fraud was to construct lines that were unnecessarily expensive to build, in order to provide larger profits to the contractors. Mark Twain captured the essence of this strategy in his marvelously cynical portrayal of "The Gilded Age:"

> *Beautiful Road. Look at that, now. Perfectly straight line - straight all the way to the grave. And see where it leaves Hawkeye - clear out in the cold, my dear, clear out in the cold. That town's as bound to die as - well if I owned it I'd get its obituary ready, now, and notify the mourners. Polly, mark my words - in three years from this, Hawkeye'll be a howling wilderness. You'll see. And just look at that river - noblest stream that meanders over the thirsty earth! - calmest, gentlest artery that refreshes her weary bosom! Railroad goes all over it and all through it - wades along on stilts. Seventeen bridges in three miles and a half - forty-nine bridges from Hark-from-the-Tomb to Stone's Landing altogether - forty-nine bridges, and culverts enough to represent them all - but you get an idea - perfect trestle-work of bridges for seventy-two miles. Jeff Thompson and I fixed all that, you know; he's to get the contracts and I'm to put them through on the divide. Just oceans of money in those bridges. It's the only part of the railroad I'm interested in, - down along the line - and it's all I want, too. It's enough, I should judge.*
>
> Mark Twain, **The Gilded Age**, Chap. 27

Monopolistic Excess and Regulation of Railroads

Fraud, monopolistic excesses in pricing, fatal accidents and cut-throat competition eventually created a situation in which it was both necessary and possible to regulate the railroads.[3] So long as the railroads were unregulated, they were able to charge what the market could bear, which led to high prices and shipper complaints during periods of economic growth and bankruptcy for the railroads and loss of railroad jobs during recessions.

Initial attempts to regulate railroads were driven by several factors: inflation during the Civil War (1861-1865), declining agricultural prices during the depression of the 1870s, rapid settlement of the west, and decline in demand for grain overseas. Between 1871 and 1874, Illinois, Iowa, Wisconsin, and Minnesota enacted the so-called "Granger Laws". These laws, though struck down in 1878 by the Supreme Court as unconstitutional, provided some examples that were followed in subsequent regulations of railroads:

- Establishment of maximum rates
- Creation of state railroad commissions to prescribe maximum rates
- Requiring pro rata rates (proportional to mileage) for the same class of goods
- Restrictions on mergers

Regulation of the railroads was finally adopted at the federal level by the Interstate Commerce Commission (ICC) Act of 1887. The ICC was given the power to regulate rates, which were required to be "just and reasonable" and non-discriminatory. Rates were required to be published, so that everyone could see whether or not they were fair. Additional legislation was needed to correct defects and omissions in the ICC Act to further protect the shipper

[3] For an excellent discussion of the economic and political factors that led to regulation, plus a detailed description of the first 75 years of rail regulation, see D. Philip Locklin, "Economics of Transportation," 6th edition, Richard D. Irwin, Inc., Homewood, IL,1966, which is the source of the information on regulation presented in this section.

The financial zenith of the rail industry was reached in the late 19th and early 20th century. The railroads basically had a monopoly on intercity transportation, and people and companies were willing and able to pay rail fares and freight rates. Regulation had eliminated discrimination in rates, but it had not generally resulted in lower rates.

However, the glitter was coming off the rail industry. Roads were being improved so as to allow rapidly improving automobiles and trucks to cut into the railroad's monopoly. The U.S. involvement in World War I brought about a period of very intensive use and very little maintenance of the rail system. In order to coordinate operations and to maximize the efficiency of the system, the federal government took control of the railroads from December 28, 1917 until March 1, 1920.[4] By the time that the railroads were returned to private operation after the war, they were in very poor physical shape, and many lacked the financial resources needed to recuperate. It was evident that there was a "strong railroad - weak railroad" problem. The strong railroads were more efficient, had better routes and served more customers. Competition among the strong railroads established the rate structure in many markets; weak railroads, with higher costs or second-rate routes, could not compete. With competition among the railroads driving prices down to levels where some railroads could not make any profits, the government recognized a need to help the industry. The Transport Act of 1920 provided some financial assistance to the railroads, established minimum rates as a way to avoid mutually destructive rate wars, and revised regulations related to rates and operations.

Over the next 15 years, the fortunes of the rail industry continued to decline, and the industry began to face serious problems that would persist for decades. The weak railroad problem remained unsolved, and many railroads went into bankruptcy. Truck competition captured some of the industry's most profitable freight traffic, and automobiles and airlines sharply cut the railroads' passenger traffic. Although the network was clearly overbuilt, with too many yards and lines, it was very difficult to consolidate facilities and the public challenged most attempts to abandon lines.

With declining profits and bankruptcy, railroads had increasing difficulty in raising capital to upgrade equipment and facilities. Operating efficiency was hampered by work rules, many of which had been negotiated with the unions at a time when the industry had been much more profitable, with different types of traffic, and more labor-intensive technology. Labor agreements made it very difficult to modify wages or work rules.

World War II provided a brief period in which the railroads once again became the dominant transport mode, as the federal government limited the use of gasoline and rubber for private travel. However, the trends toward trucks, automobiles, and air travel continued after the war, and the problems that had become evident during the depression remained unsolved, leading to pressure for further government intervention in the rail industry. The bankruptcy of the Penn Central in 1969 precipitated what was known as the Northeast Rail Crisis. The Penn Central had been formed only a few years earlier by the merger of two of the largest railroads, the New York Central and the Pennsylvania, and even on the eve of its bankruptcy it was viewed as a financially solid company. When it declared bankruptcy, it sent shock waves throughout the rail industry and the financial community. According to the Penn Central, the causes of their problems were four-fold: excessive labor costs because of union work rules and pay scales that reflected an era when railroads were dominant and operations were more labor intensive; inability to abandon unprofitable light density lines; losses in providing passenger service; and maximum rate regulation.

In the early 1970s, further bankruptcies, spectacular accidents involving hazardous materials, equipment shortages and disputes over light density lines highlighted the need for federal action to preserve the industry. The federal government faced three options for dealing with the crisis: nationalization of the bankrupt railroads, government funded rationalization of the system, and liquidation. Most in Congress were afraid of nationalization, because of the high cost of acquiring the railroads, while railroads and their customers feared political interference, especially with respect to consolidating lines and terminals and abandoning light density lines. Congress, railroads, customers, and local government officials were all afraid of liquidation, because nobody knew what would happen.

Congress eventually passed legislation that led to the government's acquisition of most of the lines owned by the Penn Central and several smaller bankrupt carriers, which were then merged into a new railroad called Conrail. Congress

[4] Locklin, p. 225

was able to act because rail labor and rail shippers strongly supported providing help to the industry. The government invested several billion dollars in upgrading Conrail's equipment and facilities in addition to paying several billion for the lines that were incorporated into Conrail.

Congress also dealt with the other problems highlighted by Penn Central by shifting passenger operations in 1971 to a new entity called Amtrak, relaxing regulation, instituting new procedures for line abandonment, and providing mechanisms to assist in gradual reduction of the labor force.

Deregulation of the Railroads

While congress was still grappling with the Northeast Rail Crisis, the rail problems spread to the mid-west. In the mid-1970s, Congress was being urged to do something to respond to the collapse of the granger roads - Milwaukee Road, Illinois Central Gulf, Rock Island, and other, smaller roads serving the region. There was some support for re-doing the Conrail process by creating a "FARMRAIL", but this was rejected as too expensive. Conrail was clearly going to cost the government more than $5 billion, and Congress had had enough of such spending.

A labor strike on the Rock Island precipitated a crisis. Instead of intervening to keep the railroad operating, the government allowed the Rock Island to cease operation. The railroad sold its best assets to other railroads, which turned out to be quite a good way to break up a railroad. The big losers in this were the union members who lost their jobs when the road went out of business.

The Carter Administration was, in general, pushing for deregulation as a way to end protection of major industry and to lower prices for the consumer. Allowing railroads to have pricing freedom was viewed as better than loss of service, by both shippers and local governments.

The end result was the passage of the Staggers Act in 1980, which eliminated much of the regulation of the rail industry. This act eliminated rate regulation for most types of rail shipments, allowed contract rates, and created new regulations aimed at expediting line abandonments and mergers. Deregulation, depending upon one's perspective, promoted innovative marketing by the railroads or led to discriminatory abuses such as those seen in the 19th century. Even railroad executives who normally claimed the former perspective sometimes admitted to the latter:

> *"The best source I have for pricing ideas is in the court cases concerning pricing abuses prior to the creation of the ICC."*[5]

Technological Innovation

Deregulation was one of several factors that allowed the railroads to remain profitable at the end of the 20th century. A second factor included negotiations with unions that allowed trains to be operated with two or three crew members rather than four or more, as well as other changes in union agreements that allowed more productive use of employees. A third major factor was technological improvement, including the remarkable advances in telecommunications and computers as well as improvements in railroad technology. Introduction of computers and advanced communications enabled the railroads to centralize their administrative activities, eliminate vast number of clerical positions, and increase the ability of managers to control operations over larger networks. Advances in rail technology included continuing improvements in materials and design for both track and vehicles, as well as intensive development of two types of rail services:

- **Unit trains** are used to transport large quantities of coal, ore, grain or other bulk commodities directly from origin to destination. Unit trains provide the cheapest of rail transportation, because they are very efficient

[5] Mark Hodak, Conrail marketing executive, explaining to my class on Freight Transportation Management how he studied rail rate discrimination in the 19th century to understand how his railroad could benefit from the deregulation of most rail freight rates in 1980.

in terms of fuel, equipment utilization, and labor requirements. By capitalizing on what railroads do best, unit trains enable railroads to compete very effectively with barges moving on the inland waterway system and with heavy trucks operating on limited access highways.

- **Intermodal operations** involve the transportation of trailers or containers by rail, truck, and ocean carrier. By using a trailer or container, it is possible to transfer freight very easily from one mode to another, so that it is possible to take advantage of each mode's capabilities. Trucks are best at moving freight short distances to and from customers. Railroads are best at moving trainloads of freight long distances; and ocean carriers are best at moving freight long distances across the oceans. A major breakthrough in intermodal operations came about in the 1980s when the ocean shipping lines and the railroads developed the double-stack container train, which allowed twice as many containers to be carried at about half the cost per container. This dramatic reduction in cost was possible only if intermodal terminals used expensive lift equipment at terminals and service could only be provided on routes that had sufficient clearances for the much higher trains (Figure 1). The potential for lower costs sparked a great many projects to build new intermodal terminals and to increase clearances on most of the major rail routes in the country. Double-stack trains made it possible for railroads to handle rapidly growing amounts of international freight as well as domestic freight such as that moved by UPS.

Figure 1 A double stack container train entering Union Pacific's Terminal in North Platte, Nebraska.
The containers were loaded in Asia, shipped across the Pacific by American President Lines, and transferred to Union Pacific at a west coast port. They would ultimately be delivered by trucks to customers in the eastern portion of the country.

- **Heavy Haul Railroading:** In 1985, the rail industry initiated a long-term research program aimed at reducing life-cycle costs for heavy freight operations. The program included laboratory testing, and monitoring of track deterioration at various locations on railroads around the country and the operation of a test track in Pueblo, Colorado known as the Facility for Accelerated Service Testing (FAST). The results of the tests enabled researchers to quantify the effects of heavier loads and better suspension systems on the deterioration rates and life cycle costs of the track structure.[6] Operating trains with heavier cars allows

[6] Hargrove, Michael B., Thomas S. Guins, and Carl D. Martland. *Economics of Increased Axle Loads – Fast/HAL Results.* Report No. LA-007. Association of American Railroads, October 1996.

railroads to save money related to fuel, crews, and equipment by moving more freight in each train. The AAR research program concluded that these operating benefits were greater than the added costs for the track infrastructure, and the industry decided to increase the maximum allowable axle loads from 33 to 36 tons. The heavier limits allow fewer trains to handle the same traffic, which not only reduces operating costs, it also reduces congestion in moving trains in and out of the most active coal mining regions, notably the Powder River Basin in Wyoming.

Summary

This case study provides an overview of the evolution of the rail industry in the United States. Portions of the rail system have gone through all of the stages of evolution of infrastructure systems, from initial testing of new technologies, to uncoordinated expansion, to consolidation, to retrenching and obsolescence. The system that remains today is far different from the one that dominated both passenger and freight transportation during the 19th century. Most of the smaller shipments and short-distance freight has been diverted to truck, and many once profitable rail lines have been abandoned or converted to rail trails. Many rail yards and terminals have been converted to other uses. Faced with competition from other modes, the railroads had to invest in the portions of their systems where they had the chance to remain competitive. Because of investment in new types of freight cars, better locomotives, improved signal systems, and more durable track structures, railroads remain the most economical way to move large shipments of bulk commodities such as grain or coal. Railroads also work with truckers and ocean carriers to move containers around the country and around the world, a type of transportation that is dependent upon investment in new types of container ships and terminals where automated equipment can be used to transfer containers from one mode to another.

The rail industry has great promise for selected services, including high speed passenger service, heavy haul freight and intermodal. Continuing advances in communications, control and materials are likely to provide further improvements in productivity, thereby helping the financial sustainability of the industry. Increasing public interest in the environmental benefits of rail may help ensure the public support necessary to maintain and expand rail service.

Lessons from the History of Railroads

Some of the lessons that can be learned from the experience of the railroads are as follows:

- New technology may enable a proliferation of new products that will be implemented without sufficient consideration of what will ultimately be recognized as the best system design.
- Competition is likely to arise for any technology and for any system. Who prospers in a competitive environment will be whoever best serves the customers within the existing regulatory framework. Just because a technology is more fuel-efficient, requires less land, or has a lower impact on the environment does not mean that the technology will prosper.
- Careful analysis can help determine what kinds of system improvements will be most helpful and how best to implement new technologies.
- Government regulation is a very important factor for infrastructure-based systems, both because of the high-fixed costs and the longevity of such systems. Government regulation of prices may be necessary to avoid destructive competition, and government funding may be necessary to allow a system with clear public benefits to be constructed or enhanced over time. Government support and regulation may also be helpful in allowing a gradual restriction of service over a slowly diminishing network rather than a collapse of service that would cause tremendous socio-economic problems for users and communities.
- As a system ages, it may be necessary to abandon facilities and services that previously were profitable in order to continue to be able to maintain and operate facilities and services that remain profitable.

Case Study
Rehabilitating Newark's 19th Century Brick Sewers

Infrastructure systems can last not only for decades, but for centuries – but only if they are well maintained. A plan for rehabilitating a system may encompass many separate projects undertaken over a period of many years. Setting priorities is essential for establishing a cost-effective program aimed at reducing risks and improving performance.

In 1990, the city of Newark, NJ embarked on a 20-year program to inspect and, when necessary, to rehabilitate its 68 miles of brick sewers that were more than a century old. Old sewers are prone to fail, with consequences ranging from the high costs of emergency repairs to disruptions to residents and businesses to collapse of city streets and possible impacts on public health. The program involved six phases. Each phase involved the inspection of a portion of the system, determination of what kinds of repairs were needed, and completion of those repairs. As part of Phase VI some of the sections that were first evaluated in the Phases I and II were re-evaluated.

Table 1 Newark's Six-Phase Program to Rehabilitate its Brick Sewers

Phase	Years	Miles Inspected	Miles Rehabilitated	Cost ($millions)	Major Source of Funds
I	1990-92	13.2	4.2	$11.1	Low interest loans from New Jersey
II	1993-96	12.6	5.5	$12.9	Low interest loans from New Jersey
III & IV	1997-08	21.3	12.1	$24	Grant from U.S. Environmental Protection Agency
V	2008	7.0	5.2	$19	Loan from New Jersey Department of Environmental Protection
VI (Planned)	2009-11	23.8	4.5	$16	Loan from New Jersey Department of Environmental Protection
Total	1990-2011	68	31.5	$83	

The inspection of the sewers produced numerous measures and photographs that documented the condition of the system, and this information was used to grade each segment of the system[1]:

- Grade 1: acceptable.
- Grade 2: minimal potential for short-term collapse, but further degradation is probable.
- Grade 3: collapse is unlikely in the near term, but further deterioration is likely.
- Grade 4: in some locations, collapse is likely in the near future.
- Grade 5: collapse has already occurred or is imminent in some locations.

Priorities for repair also took into consideration the effect of a collapse on the surrounding environment. Three levels of risk were considered:[2]

- Critical A sewers: the cost of failure and the impact of a failure on the surrounding environment would both be great.

[1] The grading technique was based upon *The Sewerage Rehabilitation Manual*, Water Resource Centre, Swindon, UK, 1994 edition. Similar grading techniques have been developed for other kinds of structures, including bridges, highway pavements, and the components of the railway track structure.
[2] The classification technique is described in *Existing Sewer Evaluation and Rehabilitation*, ASCE Press, Reston, VA 1994.

- Critical B sewers: the risk is less, but preventive action would still be cost effective.
- Critical C sewers: failure would have little or no effect unless there were numerous simultaneous failures.

Since all of the brick sewers were located under city streets, they were all considered to be critical A sewers. To manage the rehabilitation work, contracts were let for 18 separate projects, which allowed work to be done in reasonably-sized pieces and staggered over a reasonable time period.

The main benefit of the program is that the city's brick sewers, once renovated, can be expected to perform their services for another hundred years, with much reduced need for future maintenance and emergency repairs and with vastly reduced risks related to public health or collapsed roads. Similar programs have been undertaken in other cities, sometimes combined with efforts to separate rain water from sanitary wastes in order to avoid polluting waterways (Figure 1).

Lessons to be learned from this example include the following:

- A program to upgrade existing infrastructure may require decades to complete.
- Inspection can determine where infrastructure is most in need of rehabilitation.
- Risks associated with failure will vary depending upon the nature of the surrounding areas.
- It will not be necessary to rehabilitate or replace all of the infrastructure, as many sections are likely to be in good condition or in locations where failure will not cause any significant problems.
- Priorities for rehabilitation are highest for portions of the infrastructure that are in the poorest condition and that are located in areas where failure would have the greatest consequences.

Figure 1 Separating Storm Sewers from Regular Sewers on Massachusetts Avenue, Cambridge, MA
In Cambridge and Boston, as in many cities with 19th century sewer systems, when heavy rains over-taxed the system's capacity to handle the combined mixture of sanitary waste and rain water, the noisome excess poured was diverted directly into the nearby rivers or the ocean. As part of various projects aimed at cleaning up the Charles River and Boston Harbor, the two cities worked to develop separate systems for storm water, so that only rain water would be discharged into the waterways.

Project Evaluation: A Few Final Thoughts

> *"Civil engineers are problem solvers, but we need to broaden the scope of our services to include problem definition. Civil engineers must go beyond thinking in terms of project specific limits and scopes of work and become involved in system-wide, program-related decisions and policy-making to achieve long-term, sustainable solutions. We must be facilitators of collaboration among multiple agencies/owners and across jurisdictional boundaries. We must also take a leadership role in developing acceptable and sustainable methods of funding infrastructure development and asset management."*
>
> Kathy J. Caldwell, ASCE News, June 2009

Societies and civilizations advance through projects that seek to make life safer, healthier, more prosperous or more secure. History abounds with tales of famous projects, from the pyramids of Egypt and Mexico, the temples of Greece and Cambodia, the aqueducts and roads of Rome and the Great Wall of China to the canals, railroads and telegraphs of the 19^{th} century and the highways, telecommunication, dams, and water and wastewater systems of the 20^{th}. Countries have been bankrupted by bad projects, secured by practical projects, and advanced by bold projects. Individual fortunes have been made or squandered on projects, as banks and financial markets have made it possible to direct vast sums of money toward massive undertakings anywhere in the world. Large projects entail large risks, and such projects will only be undertaken if those promoting the projects can convince investors or governments to fund them. Highly capable, charismatic individuals motivated many great projects, including the Suez Canal, the Brooklyn Bridge, and the Empire State Building. However, it has not always been possible to separate the true visionaries from the charlatans and the deluded, especially when it comes to large outlays of public funds.

Project evaluation could be viewed narrowly as a set of procedures and methodologies that can be used to determine whether or not a proposal should be approved. Indeed, there are well-defined methods for assessing financial aspects of a project, and private companies and investors use these methods routinely in determining whether or not to begin projects or to invest in them. Moreover, governments today mandate environmental and social impact assessment prior to the approval of any significant project, and they use intricate economic models to estimate the effect of public infrastructure investments.

However, taking such a narrow approach misses the most interesting and challenging aspects of projects and programs, namely coming up with ideas for what could become a successful project. Someone has to come up with the proposals that will be subjected to careful scrutiny by banks, government agencies, and the public. Such proposals could emerge from a careful consideration of what society needs, they could reflect insight into opportunities offered by new technologies, or they could simply be pipe dreams that appeal to public emotions but that have little chance of success.

Much of the challenge and excitement in project evaluation deals with the earliest stages of a project, in clarifying the needs of society, in anticipating technological opportunities, and pulling together ideas or objectives for a possible project or program. Figuring out what the problem really is, defining the problem in a way that invites diverse solutions, and responding to the problems effectively and creatively can be extremely rewarding, both in terms of the success of whatever is done and in terms of the intellectual satisfaction of those involved in the process. In these early stages of project evaluation, breadth of thinking, curiosity, imagination, intuition and flexibility are more important than analytical capabilities or methodological excellence. This is when the story of a project begins to emerge.

Every project has a story, and every story has several components. What are the context and the history of the project? What are the needs that are addressed by the project? How will the proposed project meet those needs? What other approaches are available and why is the proposed approach the best approach? How much will it cost and who will pay for it? What are the broader impacts on society? What is the proper role for government? Why should the public support the project? How will negative externalities be mitigated? Projects will have financial, economic, social, environmental and aesthetic impacts, any or all of which could be important in telling the story, in evaluating whether or not to proceed or how best to proceed, and in going from preliminary thoughts toward final design.

> *"The need is to subordinate economic to aesthetic goals – to sacrifice efficiency, including the efficiency of organizations, to beauty. Nor must there be any nonsense about beauty paying in the long run. It need not pay. It is though the state that the society must assert the superior claims of aesthetic over economic goals and particularly of environment over cost.*
>
> John Kenneth Galbraith, "Liberty, Happiness and the Economy",
> **The Atlantic Monthly**, Vol. 149, No. 5, June 1967, pp. 521-26

Good solutions seldom come straight from a textbook, nor do they come from the use of complex techniques of operations research that claim to find the optimal solution to a problem. Good solutions arise from a deep understanding of the nature of the problems or needs and a clear idea of what might be done. Experts who have developed a comprehensive conceptual framework for addressing system performance will often be able to contribute a great deal to the early stages of project evaluation, especially with regard to the kinds of technical approaches that are possible. Users, abutters, and members of the public will be able to contribute their understanding of needs, identify issues that are important, and – in the aggregate if not always individually – help in applying some common sense to the discussion. Brainstorming, systematic analysis, sensitivity analysis, and scenarios can all be useful in eliciting ideas and in determining what approaches might work best in dealing with a problem.

The gestation period for very large projects may be measured in decades, and gaining approval for a major project or program may require seemingly endless political wrangling and nearly impossible coordination among local, state, and federal officials. Projects and programs therefore will need champions who are willing and able to fight the bureaucratic, political and legal battles that must be waged. The most effective leaders will incorporate social and environmental elements into the initial design and be able to use the environmental impact assessment process as a means of enhancing projects and building public support for them.

Very few infrastructure projects relate to anything that is entirely new. Most proposed projects will be viewed as potential enhancements to an existing system that deals with transportation, water resources, energy, or some other societal need. Effective project evaluation therefore requires understanding of how such systems are created, how they evolve to meet changing social and economic conditions, and how they eventually give way to obsolescence or to new technologies. Different types of projects and different kinds of issues are encountered in each stage of system evolution. In early stages, there will be a struggle to determine how best to use new technologies, how to structure facilities or networks, and in general how to become more effective and more efficient. In later stages, there will be a need to adjust the size and structure of the systems to adjust to new technologies or new kinds of competition. At the end, the challenge may be to grow old gracefully and pass away.

In recent decades, changes in technology have made some of our infrastructure systems obsolete, changes in social norms have made other systems inadequate, and changes in scientific knowledge have revealed unacceptable results from the systems we have built and continue to use. As result, most infrastructure systems initiated long ago are proving to be unsustainable, because of financial, social or environmental problems. We have become ever more aware of the need to grapple with climate change, over-dependence upon fossil fuels, destruction of forests and wetlands, contamination of the oceans, congestion and pollution within our largest cities, and ensuring adequate food and clean water for the growing global population. To deal with these issues, we will need to manage our infrastructure systems more effectively, develop new technologies, and initiate projects that enhance the sustainability of our civilization. Sustainable projects and programs will be those that will have adequate financing for construction, maintenance, and operations, a fair distribution of costs and benefits to society, and the ability to continue indefinitely without significant depletion of resources or disruption of the environment. Engineers, planners, conservation groups, businesses, politicians, and the general public will have to work together to figure out how best to move toward more sustainable infrastructure for the 21st century and beyond.

Further Reading

I love projects, don't you?
(Luther Billis, in South Pacific by Rogers and Hammerstein)

Many books and articles delve into the history of infrastructure projects and systems, highlighting the personalities of champions and opponents, the needs addressed by the project, the technologies used, the trials and tribulations that were faced, and the ultimate achievements. This bibliography lists books and articles that I have enjoyed, and I suspect that there are many more. Reading about past projects, including failures as well as successes, will provide a valuable context for anyone involved or interested in project evaluation and infrastructure systems. We can all learn from the successes and failures of those who have gone before us. The best options are not always chosen, the long-term impacts are not always considered, and the process is not always transparent, objective, or even rational. Nevertheless, many great projects have been built, many bad proposals have been rejected, and many innovations have helped to make infrastructure systems perform better.

Books about Infrastructure Projects and Programs

Al Naib, S.K., *London Docklands Past, present and future: An illustrated guide to history, heritage and regeneration*. Research Books, Romford, Esses RM6 5BY, Great Britain. (The docklands were originally constructed as port facilities in London for Great Britain's extensive international trade. As ships became larger, different types of facilities were required, and the docklands slid into decay. In the 1980s, a massive urban renewal effort converted the docklands into a variety of commercial and residential uses. The book combines concise history with many interesting photographs and maps.)

Ambrose, Stephen E. *Nothing Like it in the World: the Men who Built the Transcontinental Railroad 1863-69*. Simon & Schuster, NY, London, Toronto, Sydney, Singapore, 2000. (A fascinating story of what it took – men, materials, and financing - to build a railroad across the deserts and mountains of the American West.)

Bevis, Trevor. *Water, water, everywhere*. David J. Richards Printers and Stationers, Chatteris, Cambridgeshire, UK PE16 6AH, 1992. (The 500-year story of the construction of canals and the use of windmills and pumps to drain the fens of East Anglia.)

Carrels, Peter. *Uphill Against Water: the Great Dakota Water War*. University of Nebraska Press, Lincoln NB, London, 1999. (Local farmers and citizens fight to stop construction of a massive irrigation project.)

Clausen, Meredith L. The *Pan Am Building and the Shattering of the Modernist Dream*. MIT Press, Cambridge, MA, 2005. (The story of the issues and controversy surrounding the first of many post-WW II skyscrapers in Manhattan. "A conspicuous landmark and a testament to what many in New York felt should never have been built and should never be allowed to happen again … a social utopia based on the use of new industrial materials and new modes of production to generate new, efficient, clean-lined forms [was] displaced by the imperatives of a capitalist economy, and instead of the decent housing for growing urban populations modernists promised, flagship buildings for corporations were build." pp. 386-87)

Conuel, Thomas. *Quabbin – The Accidental Wilderness*. The University of Massachusetts Press, Amherst, revised edition, 1990. (The story of the creation of Quabbin Resevoir, which required the flooding of four towns in western Massachusetts in order to provide water for populations in the eastern part of the state.)

DeBoer, David J. *Piggyback and Containers: A History of Rail Intermodal on America's Steel Highways*. Golden West Books, San Marino, California, 1992.

Fredich, A.S. *Sons of Martha - Civil Engineering Readings in Modern Literature*. ASCE, 1989. (Pure fun!)

Gordon, John Steele, *A Thread Across the Ocean: the Heroic Story of the Transatlantic Cable*. Walker & Company, NY, NY, 2002. (Laying a cable across the Atlantic reduced the speed of news from weeks or months to seconds; after several failed attempts, the project was completed using the Great Eastern, the huge steam/sailing ship designed by I.K. Brunel.)

Graham-Leigh, *London's Water Wars: The competition for London's water supply in the nineteenth century*. Francis Boutle Publishers, London, 2000. (At the beginning of the 19th century, various water companies built competing systems for delivering running water to London neighborhoods, leading to many abuses of customers, legal battles, and eventually a recognition of the need to regulate water delivery as a public utility.)

Green, Julie. *The Canal Builders: Making America's Empire at the Panama Canal*. The Penguin Press, 2009.

Gutner, Tamar L. *Banking of the Environment: Multilateral Development Banks and their Environmental Performance in Central and Eastern Europe.* MIT Press, Cambridge, MA, 2002. (An investigation into the ways that the World Bank and others balance economic, environmental and social concerns in their attempts to promote development and reduce poverty in poor countries.)

Halliday, Stephen. *The Great Stink of London: Sir Joseph Bazalgette and the Cleansing of the Victorian Metropolis*. Sutton Publishing, Stroud, Gloucestershire, UK, 1999. (The installation of sewers and the creation of the Thames embankment as a means of cleaning up the Thames in the mid-1800s: the book is as fascinating as its title!)

Hughes, Thomas P. *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*. Vintage Books, New York 1998. (The development of management systems for complex projects including the Central Artery/Tunnel – the "Big Dig" – in Boston and ARPANET, a pre-cursor to the internet.)

Koeppel, Gerald. *Bond of Union: Building the Erie Canal and the American Empire*. Da Capo Press, Cambridge MA, 2009

Larson, Erik. *The Devil in the White City: Murder, Magic, and Madness at the Fair that Changed America.* Vintage Books, New York, 2003. (A delightful history of mass murder at the time of the creation of the "White City" along the banks of Lake Michigan to host the World's Columbian Exposition in 1893.)

Lewis, Tom, *Divided Highways: Building the Interstate Highways, Transforming American Life.* Penguin Books, New York, 1997.

McCullough, David. *The Path Between the Seas: The Creation of the Panama Canal, 1870-1914*. Simon & Schuster, New York, 1977.

McCullough, David. *The Great Bridge: The Epic Story of the Building of the Brooklyn Bridge*. Simon & Schuster, New York, 1972.

McCullough, David. *The Johnstown Flood: The Incredible Story Behind One of the Most Devastating 'Natural' Disasters America Has Ever Known*. Simon & Schuster, New York, 1968.

McDonald, Frank and Kathy Sheridan. *The Builders: How a Small Group of Property Developers Fueled the Building Boom and Transformed Ireland*. Penguin Ireland, Dublin, 2008. (A portrait of the types of individuals whose decisions fueled the real estate bubble that burst in Ireland and around the world in 2007.)

Newhouse, Elizabeth L. Editor. *The Builders: Marvels of Engineering*, National Geographic Society, Washington, DC, 1992. (Great pictures and good overviews of major projects in all areas of civil engineering; a relatively inexpensive reference that captures the excitement of big projects, although it has little detail concerning project evaluation.)

Nye, David E. *Electrifying America: Social Meanings of a New Technology*. MIT Press, Cambridge MA, 1990.

Okrent, Daniel. *Great Fortune: The Epic of Rockefeller Center*. Penguin Books, London, 2004. (How Rockefeller Center came to be developed during the depths of the Great Depression on under-utilized land in central Manhattan.)

Oppitz, Leslie. *Lost Railways of East Anglia.* Countryside Books, Newbury, Berkshire, UK, 2004. (Brief but detailed history of introduction first of the horse-drawn and later the electric tramway into the cities and towns of this region that is northeast of London. Many of the issues dealt with at that time remain central issues for modern transit operations.)

Payne, Robert. *The Canal Builders: The Story of Canal Engineers Through the Ages*. The Macmillan Company, NY, 1959.

Pellow, David Naguib. *Garbage Wars: the Struggle for Environmental Justice in Chicago*. MIT Press, Cambridge, MA, 2004.

Peters, Tom. *Building the 19th Century*. MIT Press, Cambridge, MA.

Pierce, Patricia. *Old London Bridge: the Story of the Longest Inhabited Bridge in Europe.* Headline Book Publishing, London, UK, 2001. (The 750-year history of a bridge that at one time was the retail center of London and the site of many trendy homes.)

Pole, Graeme. *The Spiral Tunnels and the Big Hill: A Canadian Railway Adventure*. Altitude Publishing Canada Ltd., Vancouver, Canada, 1995. (The construction of the spiral tunnels that, when completed in 1909, reduced the ruling grade on Canadian Pacific's transcontinental line through the Rocky Mountains, enabling longer trains, faster speeds, and less expensive operations.)

Reisner, Marc. *Cadillac Desert: The American West and its Disappearing Water*. Penguin Books USA Inc, NY, NY, 1993. (This book documents the struggles, by politicians and government officials in Los Angeles and elsewhere, to find and divert water for agriculture and cities.)

Richmond, Peter. *Ballpark: Camden Yards and the Building of an American Dream.* Simon & Schuster, NY, London, Toronto, Sydney, Tokyo, and Singapore, 1993. (The construction of a new, old style, urban ballpark that incorporated structures and designs from Baltimore's industrial past.)

Ridgeway, James. *Powering Civilization: the Complete Energy Reader*. Pantheon Books, NY, NY, 1982. (Ridgeway compiles readings about the various forms of energy, tracing the extraction, transportation, and use of coal, oil, natural gas, nuclear power, and alternative energy sources. The readings provide compelling insights into the powerful forces that have affected the exploitation of energy sources.)

Rose, Mark H. *Interstate – Express Highway Politics, 1941-1956*. The Regents Press of Kansas, Lawrence, KA, 1979. (The politics that influenced the design, location and financing of the Interstate Highway System.)

Sabbagh, Karl. *Skyscraper: the Making of a Building*. Penguin Books, NY, NY, 1989 (The building of the 50-story Worldwide Plaza in New York City.)

Schodek, Daniel L. *Landmarks in American Civil Engineering*. MIT Press, 1987 (Short articles on more than 100 projects that were selected by the ASCE as notable achievements.)

Standiford, Les. *Last Train to Paradise: Henry Flagler and the Spectacular Rise and Fall of the Railroad that Crossed an Ocean*. Crown Publishers, NY, NY, 2002. (Construction of a railroad from Jacksonville to Key West, a spectacular feat that opened southern Florida to development and transformed Miami from a tiny port into a major resort destination.)

Taurancac, John. *The Empire State Building: The Making of a Landmark*. Scribner, New York, 1995.

Talese, Gay. *The Bridge.* Walker & Company, NY, NY, 2003. (A history of the construction of the Verrazano-Narrows Bridge that focuses on the ironworkers and others who actually built it.)

Tsipis, Yanni K. *Images of America: Building the Mass Pike.* Arcadia Publishing, Charleston, SC, 2002. (One of the popular "Images of America" series, this is an annotated collection of photographs concerning the construction of the Mass Pike and its controversial extension into Boston; the author is a graduate of MIT and was both a student in and teaching assistant for Project Evaluation, the class that eventually led to this book.)

Vance, James E. Jr. *The North American Railroad: Its Origin, Evolution, and Geography*. The Johns Hopkins University Press, Baltimore and London, 1995. (A geographer's perspective on the development of the North American Railroad System.)

Wood, F.J. *The Turnpikes of New England*. Branch Line Press, Pepperell, MA, 1997. (Reissue of the 1919 classic, which provides a short description of every one of the 19th century turnpikes that were authorized by the states, constructed by chartered companies, and financed by tolls.)

Zimiles, Martha and Murray Zimiles. *Early American Mills.* Bramhall House, NY, 1973. (A history of the construction of water-powered mills and mill-towns throughout New England during the 1800s.)

Articles about Projects:

Ardila, Arturo, and Gerhard Menchkhoff. "Transportation Policies in Bogota, Colombia: Building a Transportation System for the People." *Transportation Research Record* 1817, (2002): 130-136.

Ball, Steven C. "Unconventional Expansion." *Civil Engineering*, (April 2008). (The design, construction, and notable environmental features in the largest building to achieve LEED certification; also an example of delivering a project on time and on budget using a design/build team.)

Boettner, Danita S., Don Koci, Darren L. Brown, and Bruce Allman. "Clean, Blend and Reuse." *Civil Engineering*, (July 2009): 59-65, 86. (A $35 million remediation project aimed at cleaning up contaminated groundwater and to provide potable water to Hutchinson, KA.)

Bourke, Michael R., Donald R.F. Harleman, Heidi Li, Susan E. Murcott, Gautam Narasimhan and Irene W. Yu. "Innovative Wastewater Treatment in the Developing World." *Civil Engineering Practice*, 17 (1), (2002): 25-34.

Brocard, Dominique N., Brian J. Van Wheels, and Lawrence A. Williamson. "The New Boston Outfall." *Civil Engineering Practice,* 9 (1), (1994): 33-48. (The engineering options for the new sewer system in Boston Harbor, with consideration of the geotechnical, water and pollution concerns.)

Breen, Cheryl, Jekabs Vittands, and Daniel O'Brien. "The Boston Harbor Project: History and Planning." *Civil Engineering Practice*, 9 (1), (1994): 11-32. (Very good overview of the history, need, and options considered for the whole program)

Capano, Daniel E. "Chicago's War With Water: on its way to pioneering our modern sewer system, Chicago survived epidemics, floods, and countless bad days." *Invention & Technology*, (Spring 2003): 51-58.

Curtis, Wayne, “Going with the Flow: Historic dams are being demolished or vastly altered to allow fish to return to their historic spawning grounds. Is there another way?” *Preservation,* (July/August 2003): 29-33. (Fish ladders are good for the fish, but look awful next to historic dams and mills.)

Deakin, Elizabeth. “Sustainable Transportation: US Dilemmas and European Experiences.” *Transportation Research Record* 1792, (2002): 1-11.

Dornhelm, Rachel. “Beach Master: Coney Island has been world famous for 150 years, but who remembers that its beach is the revolutionary achievement of one embattled engineer?” *Invention & Technology*, (Summer 2004): 43-48.

Drapeau, Raoul. “Pipe Dream: with creative engineering and heroic endurance, freezing, beleaguered workers pushed the Canol Pipeline through the brutal Arctic wilderness during World War II. But it was a project that should never have been started.” *Invention & Technology*, (Winter 2002): 25-35.

Fox, Richard D., William F. Callahan and Walter G. Armstrong. “Effective Facilities Planning Ensured a Successful Boston Harbor Cleanup.” *Civil Engineering Practice*, 17 (2), (2002): 25-34.

Griggs, Francis E. Jr., "Thomas W.H. Mosely and His Bridges." *Civil Engineering Practice*, 12 (2), (1997): 19-38. (One of the first to use iron for bridges, Mosely developed standard designs and worked with a prefab company to market railway and highway bridges at an advertised price per foot during the 19th century).

Griggs, Francis E. Jr. "The Panama Canal: Uniting the World for Seventy-Six Years", *Civil Engineering Practice,* 5 (2), Fall/Winter 1990, pp. 71-90. (A 20 page synopsis of the “Path Between the Seas” that focuses on the trials and tribulations of building the canal.)

Grimm, Mike. "Floodplain Management." *Civil Engineering*, (March 1998): 62-66. (This is a good, short example of a post audit. Because Fort Collins was a leader in the systems approach to flood control, they escaped their 500-year flood with little property loss and only 5 deaths versus what likely would have been $5 million damage with nearly 100 fatalities if they had not implemented their flood control projects. See Section 13.3.6.)

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Hall, Sir Peter. “Speed Rail Comes to London.” *Traffic Technology International*, (Dec 2001/Jan 2002): 25-31. (A brief introduction to the high speed rail link that had to be created between London and the Channel Tunnel.)

Hecker, George E. "Hydraulic Engineering in China." *Civil Engineering Practice*, 6 (1), (1991): 7-24. (An interesting perspective on the magnitude of China's major water resource projects.)

Heppenheimer, T.A. “Nuclear Power: Engineers Finally Made it Safe, but They Couldn’t Make it Cheap.” *Invention & Technology*, (Fall 2002): 46-56.

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Holly, H. Hobart. "Lowell Water Power System." *Civil Engineering Practice*, 1 (2), (1986): 141-145.

Izaguirre, Ada Karina. “Private Infrastructure: A Review of Projects with Private Participation, 1990-2001.” *Public Policy for the Private Sector* 250, The World Bank Group, October 2000.

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Kain, John F. and Zvi Liu. “Secrets of success: assessing the large increases in transit ridership achieved by Houston and San Diego transit providers.” *Transportation Research Part A*, (1999): 601-624.

Kaplin, John and Geoffrey Hughes. “Construction of Underground Facilities for the Narragansett Bay Combined Sewer Overflow Program, Phase I.” *Civil Engineering Practice*, **(**Fall/Winter 2008): 7-32.

Koeppel, Gerard. “A Struggle for Water.” *Invention & Technology*, (Winter 1994): 19-30. (The 70-year effort required to complete New York City’s first major water system, which was authorized in 1774.).

Langdon, Virgil L. Jr., Michael R. Hilliard, and Ingrid K. Busch. “Future Utilization and Optimal Investment Strategy for Inland Waterways.” *Transportation Research Record* 1871, (2004): 33-41. (Optimizing investments over an entire system under a series of forecast scenarios taking into account scheduled and unscheduled closures that might affect the inland waterways.)

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Mueller-Lust, Andrew. “Crystal Clear.” *Civil Engineering*, (December 2008): 38-71. (The design, construction, and notable environmental features of the Bank of America Tower at One Bryant Part, one of the first skyscrapers to achieve LEED platinum certification.)

Morrall, J.F. and T.M. McGuire. “Sustainable Highway Development in a National Park.” *Transportation Research Record* 1702, (2000): 3-10. (Examples of sustainable highway development in Canada’s Rocky Mountain National Parks, including fencing that directs animals to crossings constructed at intervals over the highway.)

O’Neill, Tom. “Curse of the Black Gold: Hope and Betrayal in the Niger Delta.” *National Geographic*, (February 2007): 88 to 117. (Profits from oil production in Nigeria have not reached the people living near the oil fields; extreme poverty, destruction of fishing grounds, pollution, and general disillusionment have fueled insurgents willing to use violence and disruption of the oil flows if their call for local control of resources isn’t met.)

Pennington, Robert A., Kristies A. Gersley, Anthonyh Gagliostro, Daniel T. Eagan, Alvin L. Zach, and John T. George. “Saving a City’s Sewers.” *Civil Engineering*, (December 2008): 61-68. (Description of a 20-year effort to inspect and rehabilitate Newark’s 68 miles of brick sewers that were originally constructed in the 19th century.)

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Reich, Leonard S. “The Dawn of the Truck: it caught on much more slowly than the automobile, partly because of the expense, partly because horses did a good job, and partly because people had to figure out just what it was and could do.” *Invention & Technology*, (Fall 2000): 18-24.

Reid, Robert L. “Under One Green Roof.” *Civil Engineering*, (March 2009). (The new California Academy of Sciences building in San Francisco houses a museum, an aquarium, a planetarium and scientific research operations in a vast structure designed for sustainability. Most notable perhaps is its 2.5 acre undulating roof, which is covered with vegetation and its stunning use of windows and interior open space.)

Rosales and Gottemoeller. “Urban Design Considerations for the New Woodrow Wilson Memorial Bridge: Competition-Winning Design for Metropolitan Washington, D.C.” *Transportation Research Record* 1740, (2000): 104-107.

Scheader, Edward C. "The New York City Water Supply: Past, Present and Future." *Civil Engineering Practice* 6 (2), (1991): 7-20. (A very readable overview of NYC's water supply history written by the director of the Department of Environmental Protection.)

Schipper, Lee. “Sustainable Urban Transport in the 21st Century.” *Transportation Research Record* 1792, (2002): 12-19. (Schipper confronts the issues related to the long-term problems with the automobile and what must be done to achieve sustainable transportation for the future, especially in very large urban areas in developing countries. This paper provides a clear perspective on what might be called “hard sustainability”, i.e. the basic environmental problems related to global warming, air quality, and dependence upon fossil fuel.)

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Sheridan, Thomas E. “The Big Canal: The Political Ecology of the Central Arizona Project.” in John M. Donahue and Barbara R. Johnston, eds. *Water, Culture and Power*. Island Press, Washington DC, 1998.

Shumay, Laurence W. “Making the Most of Transportation Infrastructure: MBTA’s South Station Intermodal Transportation Center.” *Civil Engineering Practice*, 16 (1), (2001): 67-74.

Sipes, James L. and Ron Blakemore. “Aesthetics in the Landscape: How Nevada and other States are Integrating Aesthetics into Transportation Projects.” *TR News*, (February 2007): 3-12

Tsipis, Yanni, “Central Corridor Highway Planning in Boston, 1900-1950: The Long Road to the Old Central Artery.” *Civil Engineering Practice,* 18 (2), (2003): 33-52.

Vic, Thomas E. and Mark Surwillo. “Small Footprint, Big Promise.” *Civil Engineering,* (February 2008): 66-85. (The use of new technologies to reduce the space needed for a more effective sewerage treatment plant. See Example 15.8)

World Bank. “Integrated Coastal Zone Management Strategy for Ghana.” *World Bank Findings* 113, June 1998. (This example of the many studies carried out by the World Bank shows how a qualitative process led to the identification and prioritization of environmental concerns and recommendations for management strategies to deal with these concerns.)

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Resource: Project Evaluation: Essays and Case Studies
Carl D. Martland