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Urban Infrastructure: Transportation, Public Utilities, Waste Management and Pollution Control

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Infrastructure - A Perspective

Paris, tube under the channel -- London, satellite spinning above cables on the ocean floor -- New York, concrete ribbons across undulating land -- San Francisco, silver wings soaring across the Pacific -- Tokyo and Seoul. Etched against the sky are the graceful towers of mighty bridges, the broad glass and steel fronts to massive buildings, the tall slender stacks of industries exhaling; and traced on the surface are the intricate patterns of people and their machines; and buried below are the tubes and tunnels, water pipes and power conduits and communication networks along with concrete caissons and piles that penetrate towards the earth heart seeking assurance of a solid foundation. There in the bowels of the earth lies the entrails, and there piercing the sky towers the head of civilization; but here stands humankind, the heart and mind of that civilization, asking ourselves are we standing on feet of clay?

Infrastructure Development Reflects Human Progress

Infrastructure is indeed the foundation and the framework upon which the economic and social structure of our towns, cities and nations are built. Infrastructure is the networks that supply our water, food and energy, and transport our wastes and by-products. In short the building of infrastructure reflects human progress in providing first our life sustaining needs, and second our social and psychological needs for higher quality of life through shelter, commerce, and communication.

From this perspective, we can view the history of civilizations by tracing the evolution of infrastructure - the prehistoric use of fire as an energy source, and moving from caves to constructed shelters, the systems of canals in fertile crescent to irrigate land and produce crops, the development of the wheel and the sail facilitating movement over land and on water, the aqueducts and roads of the Roman empire, and so on through time. Each development is a cycle of technological breakthrough followed by an improvement and expansion in infrastructure. But has our infrastructure become too complex, too overburdened by our demands, and too costly to build and maintain? In short, is the infrastructure on which our civilization stands, our feet of clay?

Nature's Basic Infrastructure

In viewing infrastructure as a measure of the progress of civilization, there is great danger in losing sight of the fact that nature is our most basic infrastructure. Indeed our mother earth is both the source of life sustaining resources and the sink for the waste products of human activity. It is incumbent for us therefore to care for and protect the environment from which we draw our breath, drink our water, and produce our food, and from which we extract the minerals and energy; and upon which we build our cities and our industries; and over which we move from place to place.

Mankind's Infrastructure

Networks and nodes. Mankind infrastructure then is the networks that connect us with nature and link us with each other; and it is the nodes of support for human activity. We construct these networks and build these nodes to meet a variety of purposes and needs. Table 1 defines the purpose of infrastructure by various functional groups and primary sectors of responsibility:

Table 1: Infrastructure Sectors and Responsibilities

FUNCTION	RESPONSIBILITY	
	Public	**Private**
Life Support		
Water supply and distribution	X	
Waste collection, management and disposal	X	X
Energy supply and distribution	X	X
Living space and housing	X	X
Agricultural Production		
Tools and Manufacturing		
Machines and equipment		
Factories and buildings		
Transportation		
Roads and highways	X	X
Rail lines	X	X
Canals and locks	X	
Ports		
Sea	X	X
Air	X	X
Communication		
Wire and Optical Fiber		
Wireless		
Satellites		
Broadcast		
Knowledge and Education		
Computers	X	X
Information and data		
Hard copy (books and libraries)	X	X
Electronic (magnetic media, optical media)	X	X

Building and maintaining infrastructure. As indicated in Table 1, investment in infrastructure can be undertaken by the public or the private sector, or both. The building, maintaining and paying for infrastructure is one of the most critical public policy and investment issues facing communities, cities and nations. For example, in the US, public infrastructure has been one of the critical issues of the 1990 with wide ranging debate over how to pay for development, expansion and renewal. Even in the early 1980 the 20 year needs estimate was about $2.5 trillion, about 50% of the GNP or 20% of the total national wealth (Grigg, 1991). As nations, the capital investments we made in public infrastructure are huge. On a personal level, it amounts to about half the value of the home of an average family.

Demand, Supply and Capacity Expansion. Inevitably since infrastructure is a lumpy investment, it has a fixed upper limit of capacity the day it is completed. A new freeway can carry only a maximum volume of traffic. A water line can deliver only a given amount of flow. Infrastructure planners and managers try to project future demand and build in excess capacity for the future, but often those capacities are reached or exceeded before addition capacity is available. In my experience as a freeway planning engineer for the California Division of Highways in the Los Angeles area, I observed how newly opened freeways were almost immediately used to capacity and becoming clogged and congested. Clearly, there was both a pent-up demand for freeway capacity, as well as the new freeway generating new activity creating increased demand.

When infrastructure systems are used at or beyond capacity, there is overload, congestion, reduced service and performance. The overall operation becomes inefficient and costly both to the managing agency and the user. In the public sector, it is often difficult to make decisions to stay ahead of demand and on top of deterioration and obsolescence until there is a crisis of service and a level of public inconvenience which motivates action. Generally, taxpayers don want to spend on infrastructure until they are faced with major inconvenience or poor service. While public agency planners and engineers project the needs and see the problems, legislative bodies are generally reluctant to raise the taxes and allocate the funds until the public outcry forces action. A freeway has to become a parking lot before we are willing to do something about it.

Regulated utilities in the private sector are able to do a little better. They can undertake capital investments and maintenance expenditures and pass them on to their customers as rate increases for services. Rate increases must be approved by public utility commissions, however, so there is some public oversight of such investments.

Infrastructure Cycles and the Challenge for the Future

Initially, localization of activities leads to urbanization and creates a need for infrastructure support. As infrastructure is built, it promotes further economic growth and urbanization which in turn leads to demand for expanded infrastructure. As one looks to the future, the problem might seem to be simply one of keeping up with growth. In reality the situation is much more complex with two strong forces impacting on the viability of infrastructure systems:

Infrastructure development promotes growth. As cities or countries develop and grow, so must the infrastructure needed to sustain and support growth. The challenge is how to maintain and expand infrastructure in a well planned, efficiently managed and cost effect way. The basic laws of nature seem to apply to infrastructure as well. There are life cycles for infrastructure from construction to obsolescence, and the service life greatly depends on design capacity versus growth in use, the quality of initial construction, the application of good systems management and operation, and level of maintenance effort. The dynamics of infrastructure life cycles are very much the problems and issues that must be dealt with by government public works agencies and private sector companies.

Deterioration, Maintenance, Replacement. The other force at work is like the 2nd Law of Thermodynamics. Without an input of energy, a system will tend to run down. So it is with infrastructure. Both use and aging take their toll in deterioration of the physical integrity and the service capacity of infrastructure. Maintenance is the only answer to the problem, but maintenance takes resource investments of money, machinery and labor. Again, it is a major challenge for the public sector, especially when budgets are tight, to convince taxpayers to spend money ixing potholes The other side of the coin, however, is the cost imposed on individuals from poor quality public infrastructure. Bad roads increase the cost of operating private vehicles. These costs have to become large enough to the individuals in society, before that society of individuals will seek collective action.

The Wasatch Front of Utah :
An Example of Infrastructure Evolution

Although my part of the world is relatively young in its settlement and urbanization compared to your cities in Korea, or the rest of Asia or Europe, the settlement of the western US can give us a perspective of infrastructure evolution over a foreshortened time horizon. One hundred fifty years ago this July, a wagon train of settlers entered the Salt Lake Valley in Utah. There first activity was to construct small dams on the mountain streams to divert their flow onto the valleys hard dry earth so they could plow and plant crops. These small diversions and ditches were the beginning of the water development infrastructure that was needed to support this outpost of civilization. Even before the first building was erected a plan for their new city was laid out. It was reported that their leader and city planner, Brigham Young, determined the width of the streets by the distance it took to turn his horse draw wagon around. By luck and good foresight this resulted in the spacious wide streets found in Salt Lake City today. The first trails made by the wagons rolling west to the Rocky Mountain areas, and on to Oregon and California, became dusty rutted roads. The fastest communication was mail carried by the *Pony Express,* until 1861 when east and west coast crews connected their telegraph lines in Salt Lake City. Transportation infrastructure took a major leap forward with the transcontinental rail way project. Crews starting from San Francisco raced to lay their rails to the East while crews from St. Louis pushed to the West. The lines met and were connected at Promontory Point, Utah, in 1869 with the ceremonial driving of a gold rail spike and Salt Lake City became known as the Crossroads of the West. A new era of commerce and development was begun. Soon phone lines paralleled the rail lines, bringing urban center east and west together with the marvel of instantaneous voice communication over long distances.

With the population increase and economic development by the 1920 and early 1930 , water and energy infrastructure were becoming the limiting constraints to urbanization and growth of the West. This ushered in the era of large water development projects on the major western rivers. Hoover Dam was built near Las Vegas and Glen Canyon Dam on the Colorado River near the Utah/Arizona border, and Salt Lake City like other urban areas of the west benefited from hydropower generation, and municipal and agricultural water. With abundant energy and cheap water, the development of the west surged into the 1950 , when the nation undertook the linking of every major urban center in the US with the interstate highway system.

By the 1960 and 70 the waves of urban growth in the Salt Lake valley were beginning to overtop the capacity of the infrastructure, and at the same time concerns for environmental health and carrying capacity of critical resources were coming to the fore. With a strong economy through the late 80 and early 90 , Utah has become known as oftware valley because of the large number of computer and software companies. The region has attracted new companies and in-migration has added to the population growth and urbanization. Now in the 1990 , the freeways are clogged with traffic congestion, water supplies have been mostly developed; rivers, streams and lakes are threatened by pollution from municipal and industrial waste and heavy recreational use; and air quality is deteriorating. Infrastructure is taxed to its capacity and mother nature is being abused.

Such problems and opportunities often become the drivers of political action. When you recall the Seoul Summer Olympic Games, the following may sound familiar. For nearly twenty years Salt Lake City has pursued the honor of hosting the Winter Olympic Games. To strengthen its bidding position, upfront investments were made in winter sports venues such as ski jumping, ice rinks, and bobsled runs. The gamble paid off, and Salt Lake was selected to host the 2002 Winter Olympic Games. The realization that the Games will impact the infrastructure even beyond the growing problems of congestion has been the catalyst for political action. This year the legislature approved a $1.3 billion dollar project to completely rebuild 17 miles of Interstate Highway 15, Salt Lake Valley major artery. The project is slated to widen the traffic lanes in both directions from 3 to 5 lanes, plus a high occupancy lane, completely raze and rebuild 117 deteriorating bridges and overpasses, and add modern monitoring and computer based traffic management systems. At the same time, a new $40 million light rail system is being constructed to expand the mass transit options beyond the existing bus system. Plans are also underway to expand the capacity of the existing Salt Lake International Airport. The investments are substantial, but the cycles of growth and infrastructure deterioration have taken there toll. The investment must be made, or the city will strangle from its own congestion.

Unfortunately the magnitude of financial commitment for these projects has consequences for other state supported services. Other State agency budgets were cut across the board, and the funding for public schools and universities was threatened. Furthermore, the managers of our public water supply and environmental agencies see areas of the State including the Salt Lake Valley where water infrastructure needs expansion, and fear that water problems will be neglected with so much money going to transportation.

These circumstances described for Salt Lake Valley are simply a illustration of the fact that most urban areas face similar infrastructure challenges. As Executive Director of the New York State Energy Research and Development Authority in the early 1980s, we were trying to improve the robustness of the State energy infrastructure through a number of means, among them such projects as redevelopment of small hydropower sites, tapping renewable energy sources, reclaiming energy from wastes, and pursuing a wide range of conservation measures. At the same time we were painfully aware of other problems of New York the deteriorating infrastructure: a decrepit subway system, leaky water distribution lines, and crumbling bridges -- all due to years of neglect and lack of preventive maintenance. Unfortunately the delay of political inaction and the publics unwillingness to pay, only lead to bigger problems and bigger bills in the future.

Infrastructure in the 21st Century - Concepts and Tools

Planning and Management Responsibility

Infrastructure development and operation requires a responsible organization (public agency or private company), experienced personnel, equipment, and investment capital and operating and maintenance funds. Typically these organizations have evolved with the infrastructure according to the culture, political subdivisions, economic structure and practices in various countries. In the US for example, the types of organizations managing infrastructure can be classified along the following lines:

Table 2. Infrastructure Management and Organizations

Public

- Municipal (City Public Works Department)
- Country or regional (Public Works : Roads, Water, Solid Wastes)
- State (Transportation, Water, Environmental Quality)
- Federal (Transportation, Water, Environmental Quality)

Quasi-Public (Taxing authority with specific responsibility)

- Improvement Districts (Water/Sewer, Streets)
- Authorities (Usually chartered by State Legislatures)
    - Airport
    - Ports
    - Energy / Power
    - Thruwats (Toll Roads and Bridges)
    - Mass Transit (Subway, light rail, Bus)

Private (Government regulated utilities, new being deregulated)

- Energy / Power Distribution
- Telephone and Communications
    - Wires
    - Wireless (Cellular phines, Satellite)
- Common Carriers (Airlines, Railroads)

Considering the complexity and extensiveness of infrastructure at all the levels, it is not surprising that there are literally tens of thousands of public and private organization involved as infrastructure source providers across the US. Furthermore, most of these organization do not operate in isolation from others since significant coordination is required among organizations of similar responsibility, for example roads, highways, and freeways; or water supply systems. Regardless of the size and scope of an agency infrastructure responsbilities, all of them must engage in a common set of functional activities as shown in Figure 1 (after Grigg, 1991) in order to successfully meet their obligations to provide quality service to the users or customers.

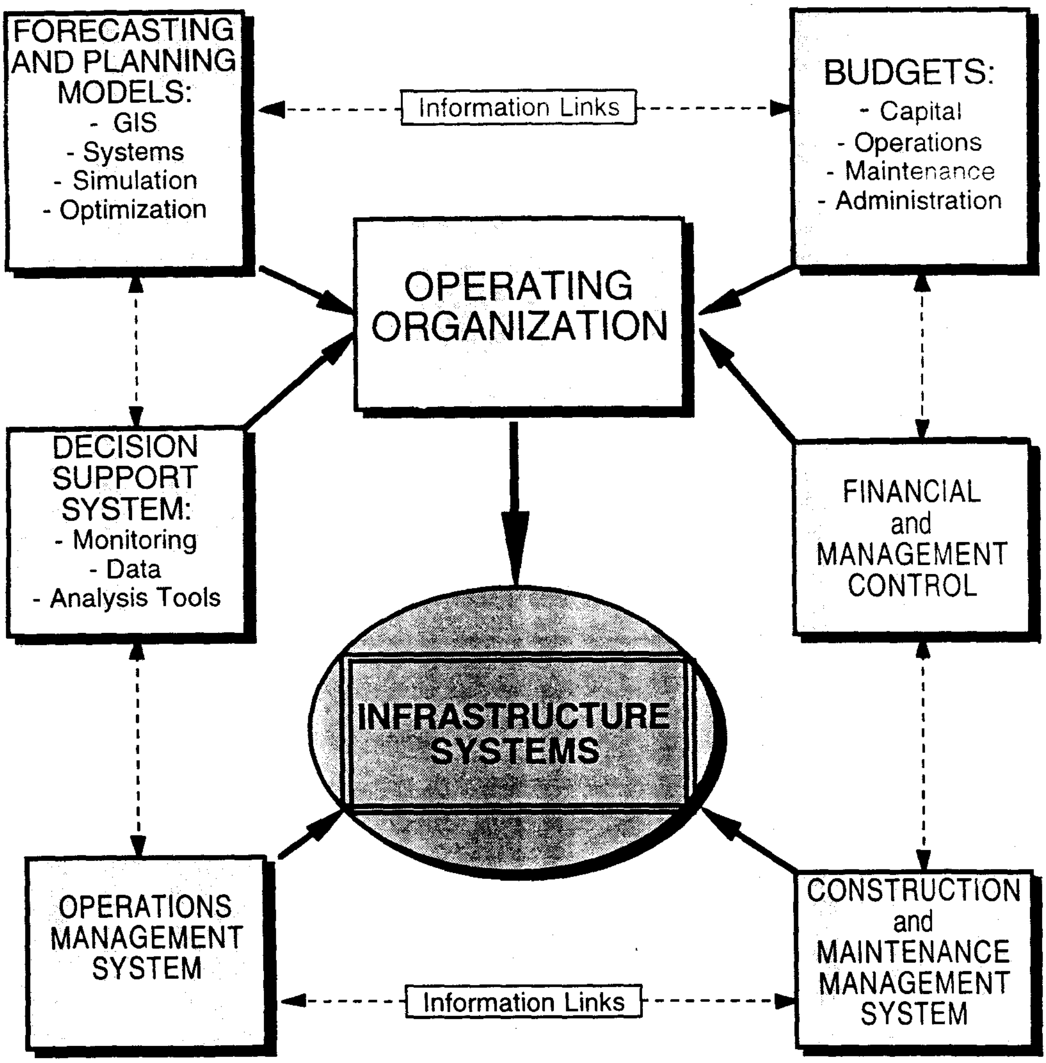

Figure 1: Functional Activities and Management of Infrastructure

GIS and Other Computer Based Tools: A Water Supply Planning Example

In this presentation, I have time to discuss only two, but a very important two, of these functions: (1) Forecasting and planning, and (2) Project construction and maintenance. The forecasting and planning function is critical in providing high quality infrastructure services to users. Without adequate planning for changing demands, demand can exceed supply, and systems can become overloaded and congested. This reduces services, and rationing or other measures are required to avoid system failures. Powerful computer based modeling tools now available are of significant value in planning and management of infrastructure. Since infrastructure is typically a network of links and nodes overlaying spatial distributed demand for services in a region, a geographic information system (GIS) is an ideal model base for infrastructure demand forecasting and planning.

Over the past 5 years, another engineer, an economist, and I have worked with the multiple tiers of agencies and local governments charged with providing municipal, industrial and agricultural water supplies for the urbaized Wasatch Front region of Utah (Bishop, et. al., 1995, 1993,1991, 1990, 1988). These overlapping jursdicitions shared common watersheds and sources ground and surface water supply, but were unable to agree on a common set of forecasts that would allow for coordinated planning for using the limited water supplies available. Our team proposed a GIS based modeling approach designed and built in such a way that all the data inputs and model functions would be open and transparent to the user. As illustrated in Figure 2, three levels were considered in structuring a model for water demand forecasting and related water supply planning.

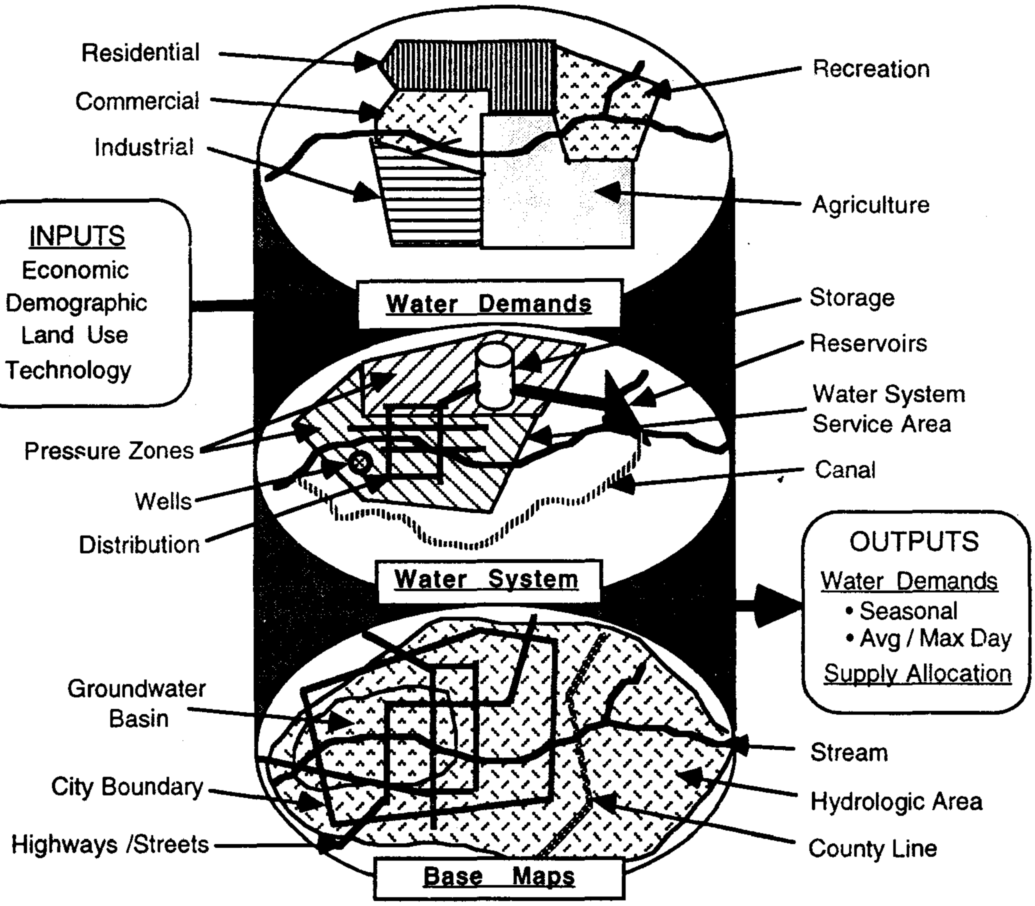

Figure 2. GIS Layers in the WFWDSM

Layer 1 - Base Maps: The base maps, digitized directly from county planning maps for the study area, provide the general geographic information for the study region. The base map layer shows the physiographic features, roads and highways, and the geographic, hydrologic, and political boundaries which are important to planners in making and aggregating demand forecasts.

Layer 2 - Water System Boundary and Pressure Zone Maps: The water system service area and pressure zones boundaries form the next map layer. This GIS layer is linked to the water supply data base which contains information on the water system facilities. Water supply sources are divided into four categories: groundwater, surface water, imported water, and agricultural water. Information on the water system infrastructure including water storage, conveyance, transmission and distribution systems, treatment plants, dual systems, and waste water reuse facilities are preserved in the data base. Capacity limits are also maintained for each source in terms of hydraulic, hydrologic and legal constraints. Statistical distributions reflecting uncertainty in surface water supplies are included. Information on proposed future supply sources were also being entered into the data base.

Layer 3 - Water Demand Sectors: Since water demand in each water system pressure zone must be met by available and future supplies, the water demand layer is built up by pressure zone. Land use and zoning maps are used to identify corresponding water demand sectors of single family residential (of different lot sizes), multiple family residential, industrial, commercial, agriculture, and public uses. Each of these water demand sectors is represented by a different color on the GIS map, and each has a separate statistically estimated water demand function (equation) associated with it. Industrial demand functions are specified by Standard Industrial Classification (SIC) categories. Demand for irrigated agricultural areas is based on consumptive use equations for various crops. The effect on water demand due to weather conditions (temperature and rainfall) and price variation is simulated by selecting values for these variables from statistical distributions.

Model Operation. Model is driven by a menu system presented to the user. The menu commands offer the user three (3) options to explore hat-if scenarios through a variety of demand analysis, planning forecasts (population, economic growth, etc.), and water supply allocation options.

1. *Demand analysis.* Each water demand sector has an associated demand function. The demand analysis options enable the user to modify the independent variables in the demand function, e.g., lot size, family size, price, dual system, etc., to analyze their effect on the water demand. The water demands for each use sector are summed for pressure zones, systems and the region. The motivation for improving methods for predicting demand is to make possible improved estimates of how much, where, and when additional increments of supply and related facilities should be developed.
2. *Planning*: In the planning mode, future water demand can be forecast by population projections or by changing land use by recoloring an area on the demand map layer to represent a different water demand sector. The model has a built-in population projection model from a regional planning or population can be input directly by the

user.

3. *Supply Allocation*: The model keeps an inventory of the current and proposed supply sources. The data for each source are stored and may be modified by the user. Data include source location, cost, quantity, quality, water system pressure and the zone served by the source. When the water demand projection is done, the model matches the available supply sources with the projected demand. The default matching is least cost but may be changed by the user. If the demand cannot be met by current supply sources, the model suggests which proposed sources be built to meet the demand and reports the total operating cost. On the supply side a number of exogenous factors can also be input to the model in order to achieve a realistic allocation of water supplies to meet demands. These include introducing new sources of supply, making or modifying service area interconnections, changing in supply system configurations, and recycling or reclaiming waste water.

Alternative institutional arrangements impacting water demand and supply transactions may also be imposed on the model to determine whether they facilitate or impede supply allocations. Examples are changing water service boundaries, modifying storage, transfer and treatment facilities, and transferring water rights.

Other GIS Application to Infrastructure. Likewise, working from GIS and other statistical databases, infrastructure models for transportation systems, energy production and distribution, and environmental quality management can be developed. GIS as a planning, design and management tool allows users to explore a variety of uture scenarios and their corresponding implications for capacity expansion systems operations, and maintenance. Furthermore, GIS is rapidly replacing the design and s built drawing and blueprints as the way to maintain system information and data.

The Design/Build Strategy -- The Salt Lake Valley Interstate-15 Project

Good forecasts are critical to good project planning for capacity expansion, but given the high cost of capital and the social and economic disruption of large infrastructure projects, it is equally important to efficiently design and build projects. The standard approach is first to design, then bid and then build. This sequential process considerably lengthens the time to project completion thus increasing the overall cost, as well as personal and social inconvenience. To overcome these problems new parallel approaches such as esign-build and project ast-tracking have been successful in bring projects to completion in shorter time at lower cost and higher quality. More large scale infrastructure project are using these strategies, including the beautiful new International Airport at Inchon, Korea. We also have such a project beginning at our doorsteps in Utah. We hope it will be an excellent example of the efficiency and value of the design-build approach.

The existing I-15 Corridor was built during the 1960 to serve projected needs through the 1980 . Time, traffic, and weather have taken their toll on the condition of the roadway and structures along the I-15 Corridor. Furthermore, current traffic demands have far exceeded the original projections which results in frequent traffic congestion along the corridor.

The Utah Department of Transportation (UDOT) decided to accomplish the reconstruction of the I-15 Corridor through a single design/build contract. There are three important goals in using the design /build approach:

1. *Time*: The urgent need complete construction so as to minimize the disruptions to the commuting public and adjacent communities, and to support a successful 2002 Winter Olympics.

2. *Quality*: A well-designed, high quality highway that is durable and minimizes future maintenance expenses, and

3. *Cost*: Since the project is financed with predominantly State funds, it must meet a requirement of a reasonable and prudent cost.

The design-build approach meets these goals through a flexible design/build arrangement so the contractor is able to plan, design, build, control and maintain the project and at the same time provide an assurance of quality.

The basic elements of design/build are:

- A single contractor who, because of the tight time frame, requiring work on almost the entire corridor at the same time, controls both the work sequence and the maintenance of traffic for the entire corridor.

- Performance specifications which, because of construction constraints posed by winter weather within the tight time frame, encourage creative and innovative design and construction solutions in the critical areas of soil consolidation and enhancement, structures and pavement design, and maintenance of traffic.

- Contractor Quality Assurance/Quality Control (QA/QC) which allows the contractor to control the quality of the construction on the job, while the owner/agency maintains a Quality Assurance oversight role.

- Early construction starts (fast track) which allow design and construction to take place simultaneously for individual design elements (i.e., a bridge structure). This is coupled with expedited design oversight reviews (vice detail review) which use an ver-the-shoulder process at the designer office and concurrent with start of construction.

- Quality is traditionally ssured by strict specifications and/or actual directed design elements (i.e., pavements and bridge types), exhaustive detail design reviews, QA/QC by the agency including inspection, testing and control. In order to provide maximum flexibility to the design/builder, the responsibilities and the isk is shifted from the agency to the design/builder. Therefore, an assurance of quality has been incorporated into the project by:

  -Performance criteria or goals incorporating the benefits of Value Engineering up front.

-Long term maintenance responsibility by the contractor in those areas of critical quality which forces life-cycle cost minimization in the design and incorporation of up-front quality.

-Best value (price and other factors) design/build contract award which makes quality a major factor in the selection of the design/builder, including a Request of Qualifications (RFQ) phase to narrow the number of proposers based on quality of organization, experience, financial capacity and past performance.

-ISO 9001 registration (certification) which requires the design/builder to establish procedures and standards for quality, and use them.

-Award fee ($50 million) incentives to reward (throughout the term of the project) the design/builder for successful execution in the areas of schedule, quality, community relations, etc.

-Stipends to each of the final proposers to acknowledge that the process is asking for more creativity and innovation up front.

As interesting footnotes : (1) the total Request for Proposals (RFP), over 40,000 pages and 2100 drawings, was issued on 4 CD ROM's in order to save the cost and bulk of handing paper, and (2) the I-15 project will be the first time that most of these processes, procedures and provisions have been used on a major, publicly funded, reconstruction project of an Interstate Highway.

Summary

To avoid the prospect and possibility that our societies and economies are standing on infrastructure that is like feet of clay, the question is what can be done to approach our infrastructure planning and development in a more comprehensive and rational way? Not surprisingly there are no easy or simple answers, but this paper has discussed approaches, processes and tools that can help. Still there are particular needs for better and more effective methods and tools that will enable us to meet the twin challenges of growth in demand and infrastructure deterioration in the future. These are:

- More effective handling of data and information for planning and management

- Better tools for forecasting needs under various conditions and scenarios of the future.

- More efficient approaches to designing and building large scale projects

- Better and more cost effective systems of management and maintenance for existing infrastructure investment.

- Improved understanding and exchange of information between responsible agencies, the public and the political decision makers.

- Privatization of services where conditions of competition can exist

Our challenge as planners, engineers and social scientists is to help develop those tools and approaches that will be of real benefit to the functions and processes of our responsible infrastructure organizations.

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