Infrastructure Management for Tren Urbano

by

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Abstract

Infrastructure provides a foundation on which to build a strong nation. Our ability to move people, goods, and ideas in an efficient and effective manner is strongly dependent upon the condition and performance of our infrastructure assets. America has been very successful at building new infrastructure assets to meet the needs of our growing economy and nation, but we have not yet established the mindset that these assets need to be efficiently maintained throughout their entire lifecycle. As a result, our infrastructure has deteriorated at a faster rate than we have been able to maintain it.

The concept of infrastructure management has arisen from this dilemma, and is being used by owners to assist in maintaining their assets under capital constraints. Infrastructure management is the method by which public officials attempt to balance their perceived infrastructure needs with their available funding resources. Modern methods and strategies are giving owners much more insight into their own decisions based on real cost assessments.

Common infrastructure management strategies are based upon lifecycle planning, and include integrated project delivery methods, innovative financing plans, and the use of computer-based infrastructure management systems. These strategies have been developed and introduced to alleviate the pressures on public infrastructure providers to cut costs while improving services. By basing these analyses on lifecycle costs, owners can equitably decide between alternatives.

This thesis will look at how infrastructure management has been and is being used by infrastructure providers. Assessments of different approaches will be made and recommended options and strategies for the continuing success of infrastructure asset management will be identified. A survey that has been used to determine the current infrastructure management policies and practices of North American urban rail transit agencies will also be discussed. The results of this survey will provide a broad view of the policies, practices, and opinions of each agency in order to determine their opinions of and current status regarding infrastructure management.

Based on the findings of this research, recommendations will be put forth to aid in the (1) future development of infrastructure management systems and processes to better serve owners' needs and (2) utilization of project delivery methods that create better incentives to consider lifecycle costs. Specific recommendations will be directed towards Tren Urbano, the urban rail transit system being constructed in San Juan, Puerto Rico. Tren Urbano is being built as a Federal Transit Administration Turnkey Demonstration Project. This project provides a relevant example of both the implications of delivery method on infrastructure management policies and the initial variables affecting implementation of effective infrastructure management.

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1 Introduction

1.1 General Review

1.1.1 What is Infrastructure?

The term 'infrastructure' is a relatively new one. Most sources trace the term to the French in the early twentieth century, while several researchers claim that Winston Churchill can be credited with its first uses. Regardless of where the term first came from, it is a very modern concept. Even in the last twenty years, the term's usage has grown tremendously, thanks to some well-timed, if not semi-alarmist publicity. What in the 1980's and earlier was considered 'public works' is now being considered as 'infrastructure.' In fact, the terms have been interchangeable in recent years (Grant 1993). This seems to indicate a very modern appreciation of the systemic nature of our nation's infrastructure and of the role infrastructure plays in today's society and economy. But what exactly is meant by the term? Definitions typically focus on physical assets.

- In 1974, the American Public Works Association (APWA) defined public works as "the physical structures and facilities that are developed or acquired by the public agencies to house governmental functions and provide water, power, waste disposal, transportation, and similar services to facilitate the achievement of common social and economic objectives" (Hudson 1997).

- The Congressional Budget Office in 1983 treated infrastructure as "including highways, public transit systems, wastewater treatment works, water resources, air traffic control, airports, and municipal water supply" (CBO 1983).

- The World Bank, in its efforts to study infrastructure in the developing world, defines infrastructure broadly as "electric power, irrigation, transport, telecommunication, water supply, and sanitation" (Israel 1992).

- The Massachusetts Bay Transportation Authority recently released an RFP (Request for Proposals) for a capital asset management system to keep track of their infrastructure assets. Their definition of capital asset is given as any item "with a unit cost in excess of $5,000 and a useful life of at least one year" (MBTA 1998).

Other definitions of infrastructure have focused not just on the physical assets, but on ownership or control of those assets.

- In 1993, the US Advisory Commission on Intergovernmental Relations (USACIR), in cooperation with the US Army Corps of Engineers, attempted to develop a federal infrastructure strategy. This strategy defined infrastructure as "any type of physical capital facilities for which the participating federal agencies are responsible, whether that responsibility is direct (ownership, operation, or maintenance), through federal aid, or through regulation" (USACIR 1993).

More importantly, however, the definition of infrastructure has focused on the services provided, rather than on physical assets or ownership. While these next three definitions mention the assets of infrastructure, they emphasize all of the policies and systems that are crucial to the provision of infrastructure services.

- The Associated General Contractors of America in 1982 defined infrastructure as the nation's "system of public facilities, both publicly and privately funded, which provide for the delivery of essential services and a sustained standard of living. This interdependent, yet self-contained, set of structures provides for mobility, shelter, services, and utilities. It is the nation's highways, bridges, railroads, and mass transit systems. It is our sewers, sewage [sic], sewage treatment plants, water supply systems, and reservoirs. It is our dams, locks, waterways, and ports. It is our electric, gas, and power-producing plants. It is our court houses, jails, fire houses, police stations, schools, post offices, and governmental buildings. America's infrastructure is the base upon which society rests. Its condition affects our lifestyles and security and each is threatened by its unanswered decay" (AGCA 1982).

- A committee of the National Research Council defined infrastructure as "both specific functional modes—highways, streets, roads and bridges; mass transit; airports and airways; water supply and water resources; wastewater management; solid-waste treatment and disposal; electric power generation and transmission; telecommunications; and hazardous waste management—and the combined system these modal elements comprise." This report also identifies the procedures, management processes, and legislative policies that affect the ability to provide the infrastructure services as vital to a comprehension of infrastructure (NRC 1987).

- Hudson, Haas, and Uddin, in attempting to address the issue of infrastructure management, define infrastructure as "all these combined facilities that provide essential public services of transportation, utilities (water, gas, electric), energy, telecommunications, waste disposal, park lands, sports, and recreational and housing. Infrastructure also provides the physical systems used to provide other services to the public through economic and social actions. These infrastructure facilities and services are provided by both public agencies and private enterprises" (Hudson 1997).

These last three definitions are important because of the broad view they take in presenting infrastructure as an entire system of service providing assets and policies. But the definition of infrastructure can change depending on the perspective of the owner. Each specific definition is generally limited in scope to include only those assets that are used when providing the owner's services. This flexible, user-defined, type of definition will be used in this thesis to define infrastructure based on the services provided by any individual owner. Later, specific definitions of urban rail transit infrastructure will be used as they apply to Tren Urbano (See Appendix A).

1.1.2 Importance of Infrastructure

Whatever the specific definition, it is generally accepted that infrastructure provides the foundation upon which a strong economy, a healthy nation, and a satisfied population are built. A fully functioning network of infrastructure assets is one clear indicator that separates the industrial world from the developing world. Consider a few relatively minor activities in our lives. Our transportation network allows us to travel by road, air, or rail rather effortlessly at a reasonable cost. We always have an adequate supply of water for drinking, cooking, and bathing. That same water is carried away from us and treated when we are finished with it. Our phone calls consistently go through. These things are taken for granted, but it is implicitly understood that a well-maintained infrastructure network is responsible all of them.

The US Advisory Commission on Intergovernmental Affairs, in their effort to identify a federal infrastructure investment strategy, found that "a sound public infrastructure forms a key part of the nation's capital stock and thus plays a vital role in encouraging a more productive and competitive national economy. In addition, public works are vital to meeting immediate as well as long-term public demands for safety, health, and a clean and ecologically healthy environment" (USACIR 1993). This sort of finding seems intuitive, yet quantitatively proving such assertions has proved difficult.

Consequently, economists have long struggled with the effects of infrastructure and infrastructure investment on the economy and the nation. Until recently, the importance of infrastructure was not very well understood. In 1989, Aschauer changed the direction of the research with the publication of three papers that summarily linked infrastructure investment to aggregate productivity. Essentially, the rate of US productivity growth has been shown to directly mirror public investment in infrastructure, at a lag time of approximately half a decade (Gramlich 1994). Aschauer's work provided the qualitative basis for using infrastructure investment as an economic boost. This was soon followed by a flurry of research in this direction.

One such example is the research done by the World Bank linking the per capita gross national product (GNP) to road infrastructure density. This research, based on forty years of historical data, showed the amazingly direct link between the two for one hundred different countries.

Interestingly, the highest correlation between GNP and road mileage per capita occurred at a four-year time lag, in broad agreement with Aschauer's observations (Hudson 1997).

According to the US Department of Transportation and reiterated by the American Association of State Highway and Transportation Officials (AASHTO), every dollar invested in the US highway system will return more than $2.60 in benefits to the economy (AASHTO 1998). Such quantitative findings strengthen the opinion that infrastructure investment is vitally important to the entire nation and its economy.

Another method taken to indicate the importance of infrastructure is the 'quality of life' approach. This interesting, yet quite subjective, area tries to tie social indicators such as life expectancy, education rates, and crime rates to increased infrastructure investment. While this may seem specious at best, it could be a valuable method for qualitatively understanding the potential linkage between the two. These linkages typically show how an increased investment in the highway infrastructure leads to more leisure time, reduced accidents, or increased employment. This approach also considers the potential drawbacks such as decreased air quality (Aschauer 1990). Such work is useful to illustrate the pervasive effect of infrastructure on our lives.

1.1.3 Doomsday Statistics – Perception and Realities

Now that the importance of infrastructure and infrastructure investment on our nation and on our economy has been identified, it is useful to assess the current condition of our nation's infrastructure. Consider these facts.

- 59% of America's urban and rural roadways are in substandard condition and will need improvement. In Iowa and Colorado, this percentage is more than 85%.
- 4% of America's roads handle 40% of the nation's auto traffic and 75% of the nation's truck traffic, and continued deterioration will cause increased congestion on these vital roadways.
- More than 70% of peak-hour traffic occurs in congested conditions, causing billions of dollars in wasted time and fuel.
- 31.4% of the nation's bridges are rated as structurally deficient (unable to handle modern loads) or functionally obsolete (unable to handle current traffic volumes). In Massachusetts, New York, and Hawaii, this percentage is more than 50%.
- 70% of the nation's bridges are more than 60 years old.
- 23% of all rail transit vehicles are in deficient condition.
- 21% of all rail transit track is in deficient condition.
- 46% of all rail transit signals and communication equipment is in deficient condition.
- 48% of all rail transit buildings and 65% of all rail transit maintenance yards are in fair to poor condition.

- 22 major airports are seriously congested with passenger trips increasingly yearly.
- 60% of our nation's schools have at least one major building problem, with more than half having inadequate environmental conditions.
- 29% of our nation's communities do not comply with the Safe Drinking Water Act of 1993.
- 40% of our rivers and lakes are not fishable or swimmable.
- An estimated 300,000 to 400,000 contaminated groundwater sites exist across the nation.
- 2,100 regulated dams are considered unsafe.
- Federal infrastructure spending as a portion of Gross Domestic Product is at a fifty-year low.
- In 1978, the City of New York found that streets were being repaved at an average rate of once every 200 years, at least four times the design life. Water mains were being replaced at an average rate of once every 296 years, three times the design life.

(ASCE 1998, Hudson 1997)

These and other similar figures have been used and overused many times to indicate that America is in the middle of an 'infrastructure crisis.' These claims are not new. In 1981, Choate published an eye-opening book, *America in Ruins: The Decaying Infrastructure*. This apparently well-timed study caught the nation's eye. For some time, this latest public policy 'crisis' was used to bring attention to the real issues facing our nation's infrastructure (Barker 1984).

The pervasive effect of infrastructure on our lives and the catastrophic nature of its failures remind us that our infrastructure does need attention. The failure of the Silver Bridge in 1967 between West Virginia and Ohio resulted in the loss of 46 lives. The collapse of the Mianus River Bridge in Connecticut in 1993 killed 3 and seriously injured 3 others. The failure of an aqueduct in New Jersey in 1982 resulted in 300,000 residents having no drinking water for three days. These are just some extreme examples of infrastructure failures that remind us just how dependent we are upon the condition and performance of our infrastructure assets (Hudson 1997).

Although the 'crisis' was never as dire as it was made to seem when first brought to light, it is far from the negligible issue it appears to be when not in the news. A 1988 report to Congress concluded that "while America's infrastructure is not in ruins, it is inadequate to sustain future economic growth" (Hudson 1997). This should be alarming. In fact, the condition and performance of our nation's infrastructure has quietly become an important political issue. A recent poll conducted by the American Society of Civil Engineers (ASCE) has found the three out of four voters are concerned about the quality of their roads, drinking water and schools. In Boston, voters were more concerned about these items than about Social Security or taxes. In Seattle, more voters cared about traffic congestion than taxes. Apparently, the issues affecting the daily lives of voters are becoming significant, and many of the poll respondents indicated that infrastructure issues could affect their voting decisions.

1.1.4 Current Infrastructure Needs – Cost Estimates

It is the current fancy to attempt to identify the current infrastructure needs in monetary terms in order to affect the public policy process. It is recognized that these needs are highly conditional and not easily comparable because of differences in (1) the definition of infrastructure used, (2) planning horizon assumptions, (3) standards defining the 'norm,' and (4) data sources (CBO 1985). But the process of determining these needs is important in order to fully understand the scope of the issue. Infrastructure assets and their performance, after all, are not ends in themselves, but are a means of providing vital public services.

The American Society of Civil Engineers (ASCE) recently introduced a well-publicized effort to grade America's infrastructure on the basis of condition and performance with their *1998 Report Card for America's Infrastructure.* Based on many of the statistics given above, ASCE determined that America's infrastructure warranted a grade of D, with each mode of infrastructure receiving only C's, D's and F's. ASCE found that the backlog of investment needs totaled $1.3 Trillion over the next five years. Considering that our total infrastructure is valued at approximately $20 Trillion and is typically designed for service lives in excess of 50 years (Hudson 1997), this represents a significant portion of our physical assets that require immediate replacement and rehabilitation. The following specific investments are said to be necessary.

- Bridges - $80 Billion to eliminate the current backlog of needed repairs and keep current maintenance levels.
- Aviation - $40-60 Billion to meet design requirements and expansion needs in the next five years to avoid gridlock by 2004.
- Schools - $112 Billion to repair, renovate, and modernize schools and $60 Billion in new construction to accommodate rising enrollments.
- Drinking Water - $138.4 Billion in total needs with $76.8 Billion of that needed to protect public health.
- Wastewater - $140 Billion needed over the next twenty years to clean contaminated sites and build needed treatment plants.
- Dams - $1 Billion to repair documented unsafe dams.
- Solid Waste - $75 Billion by the year 2000 to manage non-hazardous municipal solid waste despite decreasing per capita waste generation rates.
- Hazardous Waste - $750 Billion for clean-up of documented Superfund sites over the next thirty years.

(ASCE 1998)

Additionally, the US Department of Transportation estimates that between 1998 and 2002, $263.7 Billion is needed to maintain the current physical condition and performance of the nation's highways, while $93.8 Billion is needed to improve the current physical condition and performance. This is a total of $357.5 Billion over the next five years (AASHTO 1998).

In transit, the numbers are not as staggering, but represent a substantial investment need. $39.5 Billion is needed to maintain the current physical condition and performance or our nation's transit systems, while another $33 Billion is needed to improve the current physical condition and performance. This is a total of $72.5 Billion needed over the next five years (AASHTO 1998).

Considering that federal spending on infrastructure as a percentage of Gross Domestic Product has decreased nearly 33% since the 1940's and future spending will likely continue in this direction, alternative methods of meeting these needs are necessary (Whiteside 1997, Ichniowski 1998).

The nation's latest transportation bill, the Transportation Equity Act for the 21st Century (TEA-21) is a step in the right direction. This bill, signed into law on June 9, 1998, has appropriated $217 billion over the next six years. This includes $173 billion for highway construction, maintenance and safety programs, and $42 billion for mass transit programs. This is a significant increase in funding from the previous transportation bill. Additionally, only 5% of the spending is linked to specially designated projects (Dittmar 1998). Another important facet of this bill is the requirement that funds set aside in the Highway Trust Fund not be used for anything other than transportation projects. Recent years have seen this trust fund used for deficit reduction purposes (Clarke 1998).

Though this spending does not reach the lofty spending levels deemed necessary by the American Association of State Highway and Transportation Officials (AASHTO), TEA-21 is still the largest public works legislation in US history, and it indicates a commitment on behalf of Congress to rebuild our nation's infrastructure.

1.1.5 Looking Back

By looking back at these trends in infrastructure performance and the funding requirements needed to maintain the current status of our nation's infrastructure, it is seen that a great deal of research and development is necessary to identify potential solutions. To this end, understanding some of the reasons that have led to the current 'crisis' can help to focus the search for solutions by working to avoid past mistakes. These reasons have been identified.

1. Under-investment in public works programs.
2. Lack of good management systems for infrastructure.
3. Failure to recognize the importance to the future economy of maintaining a sound physical infrastructure.
4. Cutbacks that have slashed public works budgets.
5. Failure to replace the infrastructure as fast as it wears out.
6. Failure to realize that lack of physical infrastructure seriously impacts the level and types of services government can provide their citizens.
7. Tendency by national, state, and local officials to defer the maintenance of public infrastructure.
8. Increased costs to taxpayers to repair and rebuild the obsolescent public infrastructure.

(Hudson 1997)

These reasons highlight the need for new methods, technologies, and attitudes towards infrastructure. The realization that improved infrastructure is important to the lives of every citizen and is fundamental to economic growth must begin to influence the planning and budgeting of public policy. No longer can we continue to throw money at new construction projects while neglecting the maintenance needs of our existing infrastructure. Continued investment in both maintenance and new construction, based on rational decision-making, is crucial to our nation's competitiveness.

1.1.6 Urban Rail Transit Agencies

Transit is not immune to these concerns. In fact, in some respects the effects are amplified, due to transit's dependence on subsidies. Urban rail transit agencies exist as a social service. Cities and regions depend on rail transit to reduce traffic congestion and bring people to the goods and services they need. It is generally accepted that rail transit is not profitable from a private sector point-of-view, but the service it provides is fundamental to both the operation of the city and the lives of its population. Benefits include reduced energy consumption, rational urban development, greater mobility of the public, greater retail sales, reduced traffic congestion, job creation, reduced pollution, and increased economic productivity. Rail transit agencies, as a result, derive their primary funding from government support rather than the fare box. In the United States, the typical rail transit agency earns less than 40% of their operating revenues from fares (APTA 1998).

A peculiar aspect of transit, indeed infrastructure in general, is the separation of capital budgets from operations & maintenance budgets. According to the American Public Transit Association (APTA), $7 Billion was spent on capital projects in 1996, while $18.5 Billion was spent on operations in 1996. 9.2% ($1.7 Billion) of the operating figure was spent on non-vehicular maintenance and 54.6% ($3.8 Billion) of the capital figure was spent on facilities, which includes most infrastructure elements (APTA 1998). These monies, if allocated jointly, could permit better repair versus replace decisions to be made on the basis of lifecycle costs, rather than on the basis of funding sources. But because federal funding is available for capital projects (i.e. new construction, replacements) and typically not for routine maintenance (i.e. repairs, rehabilitations), decisions of repair vs. replace are skewed towards replace, which in some cases is not the most effective use of funds over the lifecycle. After all, why would a transit agency spend their own money to repair an asset when the federal government will offer financing to replace the same asset.

1.1.7 Capital Investment vs. Maintenance Spending

This issue of capital versus maintenance budgeting raises also some interesting problems with the current state of infrastructure. It may not be readily apparent why the distinction is drawn between capital spending and maintenance spending for infrastructure. The initial aim of such distinctions is to protect capital proposals from general budgetary constraints. This fails to recognize the functional aspects of infrastructure, and the need to address service provision from a broader level.

The similarities in purpose between maintenance and new construction, particularly when it involves replacing an existing asset, are difficult to separate. Typically, an optimum selection of infrastructure projects will include both new construction and maintenance of existing assets, and current budgeting distinctions might not align with these needs. A quote from the Congressional Budget Office states this thought well. "Whether any infrastructure aim is better achieved through capital or operating aid should be influenced by what yields good services at low cost"

(CBO 1986). This concept should underlie the purpose of infrastructure provision: providing necessary services at lowest lifecycle cost

1.2 Objectives

Having introduced the problem of declining infrastructure performance and the need for actions to address this issue, I propose in this thesis to:

- **Study** the various strategies that have been proposed to address or fix our nation's infrastructure problems. Many researchers and practitioners have opinions on how to approach this problem. This thesis will identify these potential solutions and will discuss their usefulness and implications. It is assumed here that these massive infrastructure needs are the result of not one large decision, but rather, countless smaller decisions. To borrow a popular phrase, it is necessary for infrastructure managers to think globally while acting locally to ensure the continued provision of infrastructure services in an efficient and effective manner.

- **Evaluate** these strategies for their applicability to urban rail transit systems. Strategies that may work for a highway department may not work in an urban rail transit agency. Scope of the infrastructure asset network, variability of assets, and incentive to provide services may change with the organization.

- **Recommend** specific actions to Tren Urbano to avoid the common pitfalls of infrastructure management. Tren Urbano, currently being constructed in San Juan, Puerto Rico, is at a crucial stage of its development, and strategies implemented now can help to ensure the long-term viability of their infrastructure asset network.

- **Propose** general actions to other infrastructure owners and managers to utilize the latest strategies and techniques in order to solve their infrastructure problems. The solution will be an on-going one that will necessitate innovation in all aspects of infrastructure provision and requires dedicated funding, political will, and the use of the latest technologies and techniques.

1.3 Research Scope and Approach

In order to reach these objectives, a reasonable scope must be established and a feasible approach must be identified. First, I will review the literature and briefly outline the current thinking and practices endorsed by academics and practitioners. By understanding the state-of-the-art in this area, I can begin to approach the issue. This literature review will also identify key figures who are working in this area that will be contacted.

Second, a large part of my data gathering will involve a survey that has been sent to and received from eight of fifteen urban rail transit agencies in North America. This survey is intended to determine the current practices, policies, systems, and opinions in the industry with regard to infrastructure management.

With these two primary sources of information, I will analyze the current practices of urban rail transit agencies in comparison with those practices endorsed by the academic literature. This comparison will yield some insight into the discrepancies between the two, and what types of strategies can be employed to realistically achieve effective infrastructure management.

1.4 Contributions

This thesis will analyze the potential solutions offered to address the current infrastructure 'crisis.' This will be done through a rational and objective process of identifying the positive and negative implications of each potential solution. The outcome of this analysis will be a new approach to infrastructure management that can help owners to achieve the ultimate goal of minimizing the lifecycle costs of providing infrastructure services.

This thesis will also identify a method for analyzing an infrastructure management process that will allow owners to self-assess their own efforts. This 'Quick Test' identifies several key aspects of an infrastructure management process and can help to understand where that process might be inhibiting the owner from managing their infrastructure assets in a fully effective manner.

1.5 Thesis Organization

Chapter 2 – Infrastructure Management
Chapter 3 – Integrated Delivery Methods
Chapter 4 – Infrastructure Management Systems
Chapter 5 – Proposed Framework of Infrastructure Management
Chapter 6 –Tren Urbano
Chapter 7 – Conclusions

Chapter 1 introduced the scope of the infrastructure crisis that is facing owners today. This crisis affects all infrastructure owners, providers, and managers, including urban rail transit agencies like Tren Urbano. It is only through a concerted effort to address this crisis at all levels and in all organizations that progress can be achieved. Chapter 2 will identify solutions that have been put forth to address the crisis and will show how these strategies have similar elements that can be drawn together under the heading of 'Infrastructure Management.' Chapters 3 and 4 will provided detailed description and analysis of two of these strategies: Integrated Delivery Methods and Infrastructure Management Systems, respectively. Chapter 5 will bring the previous four chapters together to present an integrated view of how effective infrastructure management can be implemented based on the integration of both integrated delivery methods and infrastructure management systems. Chapter 6 will introduce Tren Urbano and apply the lessons learned from all of the previous research and analysis in order to present specific recommendations. These recommendations are intended to aid Tren Urbano's infrastructure management development process, which are intended to minimize the lifecycle costs of providing transit service. Finally, Chapter 7 will conclude more generally on how all infrastructure owners, providers, and managers can implement an effective infrastructure management process, utilizing a new approach of prediction and monitoring of operations & maintenance cost.

2 Infrastructure Management

2.1 General Review

The term 'Infrastructure Management' has turned into a buzzword lately among infrastructure owners. All types of owners claim to be employing infrastructure management techniques and strategies. What does this mean? In the most basic sense, infrastructure management is the sum of the decisions, policies, and practices that are adopted with respect to the delivery of or the maintenance applied to any infrastructure asset or network of assets. So in this general sense, every owner does indeed perform infrastructure management. But it is the application of logical and intelligent decisions, policies, and practices that distinguish effective infrastructure management from ineffective infrastructure management.

The current state of infrastructure in our nation, described in chapter 1, has spurred a great deal of research in the area of infrastructure management. Most, if not all, of this research is based upon the basic premise that our nation's infrastructure needs are growing faster than our ability to pay for them. It is then proposed that innovative technology, management techniques, and/or financing strategies are needed to avoid diminished infrastructure performance. These strategies allow owners to avoid future crises by learning from the mistakes of the past and by taking advantage of the latest techniques to plan for the future. This chapter will examine these strategies and propose a new model of infrastructure management.

2.2 Literature Review

The following relevant research attempts to address our infrastructure problems with possible solutions that would allow owners to achieve the desired levels of infrastructure performance and condition without spending more money than they can reasonably raise.

2.2.1 Current Thoughts

Peyrebrune bluntly states that part of the solution is more money. Investment in the future provision of infrastructure services is crucial to our nation's ability to compete, both at home and abroad. Without the necessary funding, our national ability to provide basic infrastructure services will decline rapidly, and with it, our quality of life. Another part of the solution, however, is the implementation of processes to collect, analyze and act on good data concerning the condition and performance of our infrastructure network. Performance-based budgeting and the use of management systems need to be the basis of programming decisions and capital budgets. He concludes that more research and attention to this point is essential to helping engineers develop better ways to ensure appropriate investment in infrastructure (Peyrebrune 1997).

Haas recognizes the need for more funding, and also identifies political will and commitment to action as necessary to solve our infrastructure crisis, but then argues that even these are not enough. In fact, without the technology, skills, and management capabilities, the crisis can not even be addressed, because these implied factors are equally necessary. His premise is that these skills are normally taken for granted, but advances in each area are needed to achieve success (Haas 1997). Gohier disagrees on this point, stating that "the real challenge is less a technical one than a management one. We cannot continue managing infrastructure worth billions of dollars without comprehensive and sophisticated tools" (Gohier 1997). Both of these points are valid, however, because developing the necessary management tools has become a technical challenge in recent years.

Hudson, Haas, and Uddin also present a compelling case for the implementation of effective management tools. Past underinvestment in infrastructure maintenance, coupled with the lack of effective infrastructure principles point to the need for improved methods of management and financing for infrastructure. They argue that infrastructure management decisions are made every day by public agencies, but these decisions are based more on historical behavior than actual needs of their infrastructure network. The main basis for their work stems from the fact that, "unfortunately, public agencies have not realized the importance of performance evaluation, maintenance programming, or other important keys to successful asset management" (Hudson 1997). This may or may not be the case with each agency. But the point is well taken, because most agencies have yet to implement the tools they need to effectively monitor and evaluate the performance of their assets.

Felbinger and Price argue that the solution lies in the overwhelming need for innovation in infrastructure, indicated by the following reasons. First, there is a history of minimal innovation in public infrastructure. Second, current opportunities are available through the latest automation and information technology. Finally, service quality is increasingly in demand by the public. These proposed innovations are needed across three levels of infrastructure systems during six phases of the infrastructure lifecycle. The three levels are given as System Management, System Engineering, and System Technology, and the six phases are given as Conception, Planning, Design, Construction, Operation, and Renewal. A matrix of these two schemes can give a clear idea of where innovation can occur or is most needed. This matrix is a very relevant way to view the issues. These three levels effectively stratify the needed tasks of managing assets into their components while approaching the lifecycle from a very broad perspective.

This paper also mentions specific innovations needed by infrastructure. Two important examples given are decision support systems (or management systems) and reduction of cycle time in the infrastructure lifecycle (or increased integration). In order for infrastructure managers to increase user benefits, satisfy taxpayers, and provide economic stimulus, they need to do "more with less" and be more innovative in solving their infrastructure problems (Felbinger 1997).

Schilling approaches this problem from a different viewpoint however, in describing the limits of getting more for less. He sees fewer dollars being available to operate and maintain current infrastructure assets as well as build new assets, and this is the driving force for any innovations that must occur. His challenge to the engineering community is to develop improved methods for recognizing risk and delivering services, while considering the implications of reducing the federal government's role in the built environment. There are only three ways to accomplish this, however; doing better (or more) with less, cost sharing, or doing less. The last option is not easy or attractive, which is why innovations in operational efficiency or integration of lifecycle phases are necessary (Schilling 1997).

Vaughan also recognized in 1984 that while better planning, managing, and coordinating can stretch public dollars, a more broad strategy is required to span the gap between needed work and available funding. He suggests several options. Four of these are particularly useful. First, the engineering and maintenance standards should better reflect economic decision-making criteria and define realistic replacement cycles. Second, improving the capital planning, budgeting, and management process can avoid common problems of misallocation of precious resources. Third, he suggests charging for public services in the form of user fees. Beneficiaries of public services should pay their share of the investment. His final recommendation is to increase infrastructure investment (Vaughan 1984).

2.2.2 Key Concepts

The above referenced papers all boil down to a few key concepts. The five basic solutions given by these sources to solve our infrastructure 'crisis' are:

1. Increases in funding.
2. Innovations in all lifecycle phases and operational areas.
3. Improvements in operational efficiency.
4. Changes in government involvement with infrastructure (funding, regulatory, control).
5. Advances in automation and information technology (management & control systems)

Essentially, all of these proposals are endorsing solutions that provide for one or more of these five approaches. Each is valid. Solutions are needed that provide for increased efficiency and advanced innovations while taking advantage of limited funds. It is important that any such solutions be flexible enough to allow for the utilization of alternative delivery methods and for the use of computer-based management systems. Solutions that do this will be those that enable an owner to understand their own costs of providing infrastructure services.

Infrastructure management, sometimes called facilities management or asset management, has arisen in the last decade to address these problems and bring these solution types together. This approach typically attempts to identify strategies over the entire lifecycle of an infrastructure network that will result in reduced lifecycle costs, longer service lives, and greater performance. Ultimately, these strategies are intended to minimize the lifecycle costs of providing infrastructure services.

These strategies necessitate the development of a framework to effectively deal with all of the factors affecting the process of infrastructure management. Schulz describes a framework in terms of a five-part process encompassing all phases of the infrastructure lifecycle, including Planning, Design, Construction, Operations & Maintenance, and Monitoring & Evaluation. This framework treats all of these functions as equally important to the entire lifecycle of an infrastructure asset. Each function shares common data through a centralized management process. Since these phases have traditionally operated independently of one another, a great deal of effort will need to be expended to coordinate their efforts (Schulz 1998). Others have identified Renewal as a distinct lifecycle function, and have combined Operations & Maintenance together with Monitoring & Evaluation.

Haas presents a different framework that shows two basic levels of management needs: program/network/system-wide and project/section. The network-wide level is concerned with the data and strategies across the entire infrastructure network, while the project level is concerned with individual actions and alternatives for any infrastructure asset. This helps to make the distinction between the technical needs of engineers and the more qualitative needs of managers when collecting and distributing information. Both types of information are crucial in this coordinated framework (Haas 1997). This is very similar to the three levels for innovation proposed by Felbinger and Price.

Finally, Lemer and Wright propose an integrated infrastructure management system that provides elected officials, infrastructure managers, and administrators with the data and analysis necessary to make informed decisions on infrastructure policy. This system maintains an inventory of all assets and uses this inventory as the basis for performing certain process tasks that aid in assessing the current and future needs of an infrastructure network. These process tasks include data collection, performance modeling, alternatives, decision analysis, actions, reporting, and feedback (Lemer 1997). This expanded capital budgeting system should also be built with system engineers and operators in mind, in order to be truly integrated.

2.3 Common Strategies

An effective infrastructure management process coordinates many functions previously unavailable to transit planners, maintenance managers, engineers, and administrators and performs these functions in a systematic way. Any concept of infrastructure management must start with planning, design, and construction. Each must be performed with an understanding of the entire lifecycle of each individual infrastructure asset, and how it relates to the entire infrastructure asset network.

Typically, infrastructure management strategies are only introduced after the planning, design, and construction phases, and this accounts for much of the problems with our infrastructure. A study of building construction in Saudi Arabia illustrates this point well. It found that owners and maintenance contractors generally agree that several specific design defects have severe effects on maintenance costs and actions (Assaf 1997). Gibson makes the obvious point that by reducing the number of design and construction defects, maintenance expenditure will also decrease. These defects are generally avoidable (Gibson 1979).

These conclusions apply to infrastructure just as easily. Analyzing the sensitivity of infrastructure performance to initial design and construction standards is quite difficult. But this analysis has been attempted in order to describe both the increase in maintenance costs and the diminished performance of infrastructure due to deterioration caused by design and construction defects. The analysis used in this study linked initial conditions to deterioration rates, and linked maintenance actions to deterioration rates. Though this study made the assumption that cost was a direct indicator of quality, it was determined that higher initial quality led to lower maintenance costs in certain construction types, and to lower deterioration rates as well (Olayé 1997).

Both of these studies illustrate the lessons given in a standard influence diagram (See *Figure 2-1*), which shows that the ability to control the costs of a project are greatest in the earliest phases, and decrease as the asset enters the later phases of its lifecycle. This explains why the best time to plan for the future of an infrastructure asset is in the planning and design stages, because once construction commences, much less can be done to affect lifecycle costs and maintenance expenditures.

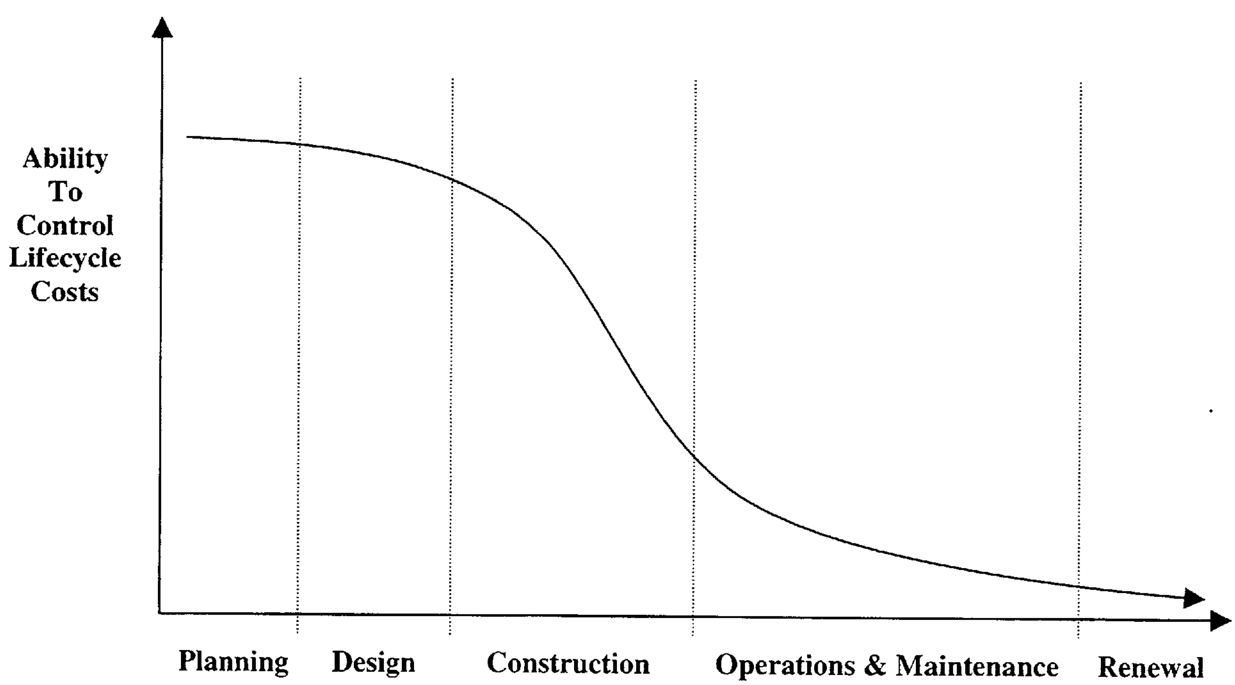

Figure 2-1 Influence Diagram (Paulson 1976)

The solutions offered earlier identified two distinct strategies for managing infrastructure. It is no accident that these two have gained in usage in recent years. Both strategies (Integrated Delivery Methods & Infrastructure Management Systems) are based upon lifecycle cost principles that work to minimize total costs of service provision. These principles have gained in usage in recent years. The following section will explain how these two strategies work, and how they utilize lifecycle cost principles.

2.3.1 Lifecycle Planning

Before introducing the two strategies, the concepts of lifecycle planning must first be addressed. Lifecycle planning takes into account the full service life of an infrastructure asset for decision-making, not simply some arbitrary initial time frame, in order to optimize the total cost of ownership over the life span of an infrastructure asset (Arditi 1996). The goal then becomes a case of trying to minimize the sum of capital and maintenance expenses over the lifecycle of an asset (See *Figure 2-2*). This allows an owner to understand the full lifecycle costs of various options, rather than just initial costs.

For instance, a new bridge construction project could present a choice between two different types of expansion joints. Joint type 1 might cost 10% less than joint type 2 to purchase and install, but might have a design service life that is half of what the design service life is for joint type 2. Clearly, the initial savings are more than offset by the fact that joint type 1 will need to be replaced twice as often. Lifecycle planning, if based on accurate cost and service life predictions, would identify joint type 2 as more economical than joint type 1, while simply considering initial costs would cause an owner to choose the less economical joint type 2, resulting in higher lifecycle costs.

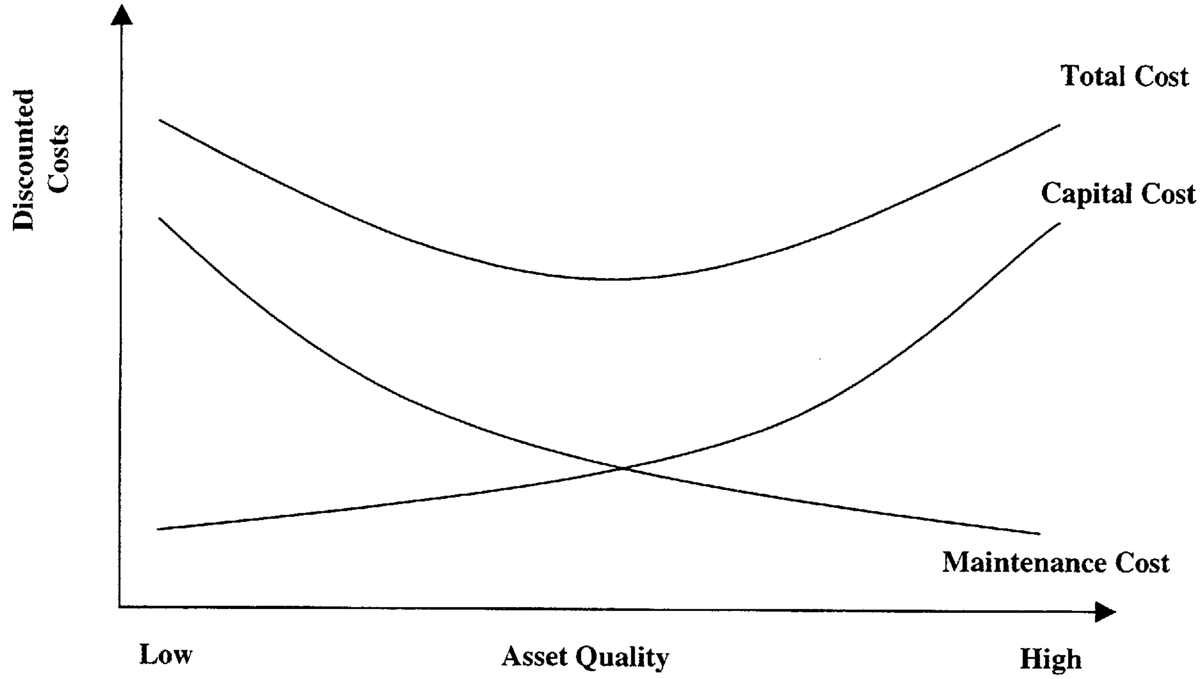

Figure 2-2 Minimize Total Costs (Cook 1987)

Plenty of studies have been done to indicate that lifecycle planning is a useful tool for owners. Arditi and Messiha have found in a survey of 195 of America's largest cities, that 40% are using lifecycle cost considerations in their municipal construction projects, some having done so for almost 20 years. Approximately 80% of these cities using lifecycle cost considerations assessed their own experience as successful. This study also found that lifecycle cost was considered primarily in the design phase of transportation projects, and cites work by Dell'Isola and Kirk regarding the significance of savings and influence on future costs possible during the design phase, as reason for this (Arditi 1996).

2.3.2 Integrated Delivery Methods

A delivery method is the way in which a project is designed, constructed, operated, and financed. The variety of delivery methods that are available provide a lot of flexibility to an owner, and one potential benefit of these is their positive effect on infrastructure management concerns through increased lifecycle planning. These methods can provide incentive to an owner to consider the implications of their decisions on all phases of an infrastructure asset and the entire infrastructure network. Essentially, by integrating any of the lifecycle phases, the owner now has a reason to consider the implications of decisions made in one phase on costs in the others. It is particularly beneficial if this incentive can be transferred to every participant in the lifecycle. This strategy will be investigated more fully in chapter 3.

2.3.3 Infrastructure Management Systems

Infrastructure Management Systems are used to provide a systematic approach to the appropriation of limited funds by considering the effects of changing policies and budgets on the entire network of infrastructure assets. These systems are typically computerized systems based around a database of network attributes. This database provides the basis for modeling and simulations to determine the best program of maintenance considering the lifecycle costs and benefits of various options performed over the entire infrastructure network.

"An ideal infrastructure management system would coordinate and enable the execution of all activities so that optimum use is made of the funds available while maximizing the performance and preservation of assets and provision of services. It would serve all management levels in the organization (public or private), and would be structured to be adaptable to all of infrastructure (Hudson 1997)."

Before computer technology was widely available or affordable, the tasks of data archival and retrievable, modeling, and optimization were simply unrealistic and all data was stored in paper form. It was not readily available or in any usable form to provide for analysis or network-level decision-making. The latest in information technology has recently enabled infrastructure managers to perform these tasks in applying the latest infrastructure management techniques and strategies.

These computerized infrastructure management system can perform many functions quickly and easily to facilitate effective infrastructure management within an organization. These functions were previously unavailable, yet are now commonplace. Though most people immediately correlate any mention of an infrastructure management system with an over-glorified database or spreadsheet, this is not necessarily true. An effective system can utilize a database as simply one task towards the goal of an effective infrastructure management process. The history, use, and design of these systems will be investigated more fully in chapter 4.

2.4 Summary

This chapter defined infrastructure management and introduced the reader to the potential solutions that have been offered to address the problems introduced in chapter 1. Ultimately, the strategies undertaken are intended to minimize the lifecycle costs of providing infrastructure services. Two strategies, each based on the concepts of lifecycle costs, were introduced as useful tools for managing infrastructure. Three others were identified but cannot be pursued here due to their specific nature.

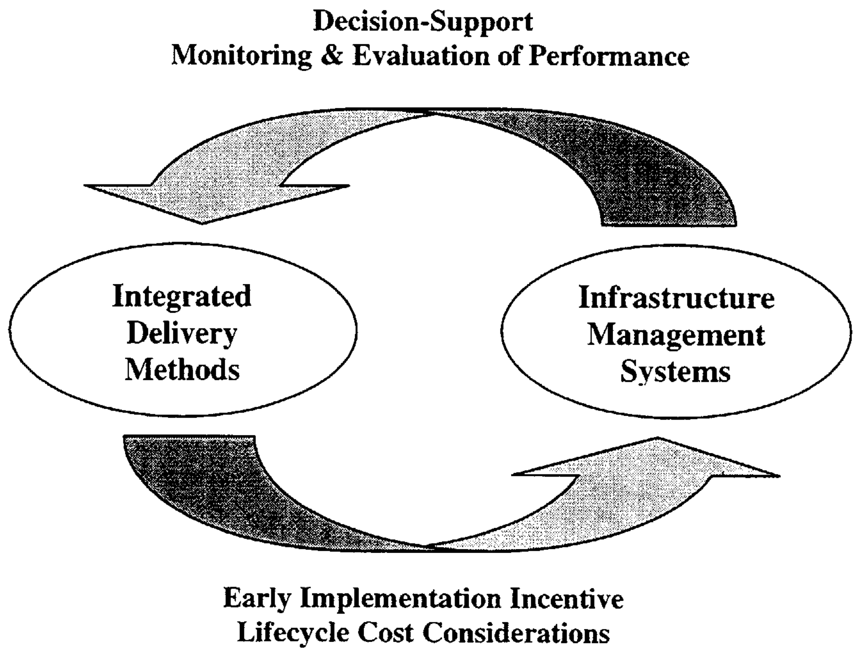

Figure 2-3 Model of Interdependency

Regarding these two strategies, one common thread that binds them together is their basic reliance on lifecycle costs. Both are based on the concept of knowing and developing the actual costs of providing infrastructure services. This relationship is shown in *Figure 2-3*. As shown, integrated delivery methods can provide the initial impetus to consider lifecycle costs, including implementing the infrastructure management system. Likewise, the infrastructure management system can provide decision-support to the planning process when considering alternative delivery methods based on performance evaluations of existing assets.

Additionally, this model of interdependency can support the implementation of other solution types. For example, understanding the actual costs of providing infrastructure services can lead to increased efficiency and innovative practices, and can assist in the comparison of current methods with innovative technologies. Utilizing this model as a basis for infrastructure management can promote effective infrastructure management.

Though both strategies can be implemented, in different ways, at any stage of an infrastructure asset's life, the most benefit can be obtained by implementing these strategies at the initial planning stages of any infrastructure project, due to the influence of decisions on lifecycle costs. The next two chapters will examine the history behind and the usage of each strategy in more detail in order to support the assertions of this new model.

3 Integrated Delivery Methods

3.1 General Review

There is a need to derive the maximum possible benefits from every dollar spent on transit and infrastructure in general. Briefly described in chapter 2 were two methods for doing this. Integrated Delivery Methods and Infrastructure Management Systems, which both rely on lifecycle planning, are two ways in which owners have chosen to manage their infrastructure assets. This chapter will investigate how integrated delivery methods are utilized in the infrastructure management process.

3.1.1 Delivery Methods

Delivery methods for infrastructure are the contracting and financing strategies that owners can use to design, build, operate, and finance projects. There are a multitude of different methods and combinations of methods that an owner can choose from to deliver a project, and there is no 'correct' method that will work best for all projects. Rather, each project's individual characteristics can determine which delivery method to choose by eliminating those methods that don't make sense. This allows delivery method and financing to be viewed as variables to be chosen in the project planning stages, independent of legislative or regulatory control (Miller 1997).

In practice, this discussion of alternative delivery methods for infrastructure has turned into a meaningless debate on the merits of 'privatization.' The debate typically degrades into an ideological harangue about the inherent inefficiency of government provided services, and whether allowing the private sector to invest in and operate government functions can bring better productivity and lower cost to infrastructure (Karlaftis 1997). This debate effectively politicizes the discussion such that no meaningful change in the current system could be instituted in order to address the nation's growing infrastructure problems.

Train operations in England were privatized recently, and performance has improved slightly. The Minister for Railways and Roads has indicated that the newly privatized train operators have breathed innovation and enthusiasm into their services, and better infrastructure management was cited as leading to better punctuality and improved performance of these trains (TTCL 1995).

The City of Indianapolis, and particularly its mayor Steve Goldsmith, has come to the conclusion that privatization was the only way to deal with the more than $1 billion in deferred infrastructure investment facing the city. By privatizing the airport and two wastewater treatment plants, Indianapolis is counting on, and seeing, reductions in capital expenses. They expect to spend less in the long run by maintaining their infrastructure now, and the private sector is supplying much of the initial capital (Short 1997).

But not everyone is convinced. In a response to an editorial in Civil Engineering magazine, the President of the New York City Transit Authority's Engineers Union predictably spoke out against privatization. He claimed that public sector costs per engineer were significantly less than the private sector, that public agencies have greater institutional memory, and that public engineers must meet a higher standard than those in the private sector (Levy 1997). As seen, this debate can quickly degrade from here into a quagmire of misunderstandings and anecdotal evidence.

To be sure, ownership and control does have an effect on performance. Ownership has been shown to independently affect performance, shown by such performance variables as profit per period, labor productivity, or production output (Vickers 1991). This perspective leads to the conclusion that the probability of poor performance decreases with decreasing public sector involvement in service provision for some infrastructure, although the benefits of private ownership in terms of performance gains have been shown to be higher in some services, namely railways, than others (Humplink 1993).

Strategically, firms wishing to remain competitive must create and take advantage of markets that reward the integration of project phases. Providing financing, becoming involved in operations and maintenance, and assisting owners in preplanning/permitting are recognized as ways in which to do this (Yates 1995). This view tends to support the integration of project phases not from a political view, but simply from the perspective of market forces that shape the competition for projects. Owners must recognize and adapt to these changes.

This chapter is not attempting to enter this debate with the intent on providing an answer or supporting one of the existing viewpoints. Rather, this chapter is attempting to present the choice of delivery method as having a distinct effect on long-term infrastructure management concerns and options, allowing owners to better understand their delivery method options.

3.2 Types of Delivery Methods – The Four Quadrants

There are countless delivery methods, and the names that describe them can be misleading at times. Industry professionals recognize a slew of names that each have their own intricacies and hidden meanings. For this reason alone, a systematic metric to evaluate each delivery method is helpful. These are some common delivery methods that will be referenced in the rest of the chapter, but this is by no means a complete list. Many variations of these common methods are possible by shifting various risks and incentives between an owner and the project participants.

Design-Bid-Build (DBB):	Design, construction, operations & maintenance, and financing are each provided by separate, independent participants.
Design-Build (DB):	Design and construction are provided by one participant, while operations & maintenance and financing are provided by separate, independent participants.
Design-Build-Operate (DBO):	Design, construction, and operations & maintenance are combined and provided by one participant, yet this participant is not responsible for the financing of the project.
Build-Operate-Transfer (BOT):	One participant is responsible for the design, construction, operations & maintenance, and financing of the entire project, generally with a long-term contract. A BOT contractor assumes most of the project's risks.
Turnkey:	This is a variation on DB, in which one participant is responsible for design, construction, and construction financing of the project, while operations & maintenance and long-term financing are handled by other third-party participants.
Super-Turnkey:	This delivery method encompasses the functions of Turnkey delivery, but also provides for long-term financing.

These methods can be defined by two variables: Degree of Integration and Financing Source. The degree of integration refers to the integration of the lifecycle phases of an infrastructure asset, while the financing source refers to the degree of financial risk taken by the owner of the project. These variables are then combined into an operational framework for understanding the diverse set of delivery methods. This combination of variables into two perpendicular axes produces four quadrants to indicate where each of the delivery methods is represented. The degree of integration is bounded at the extremes by Segmented and Combined delivery methods, while the financing scheme is bounded by Indirect and Direct sources of funds, as shown in *Figure 3-1* (Miller 1997).

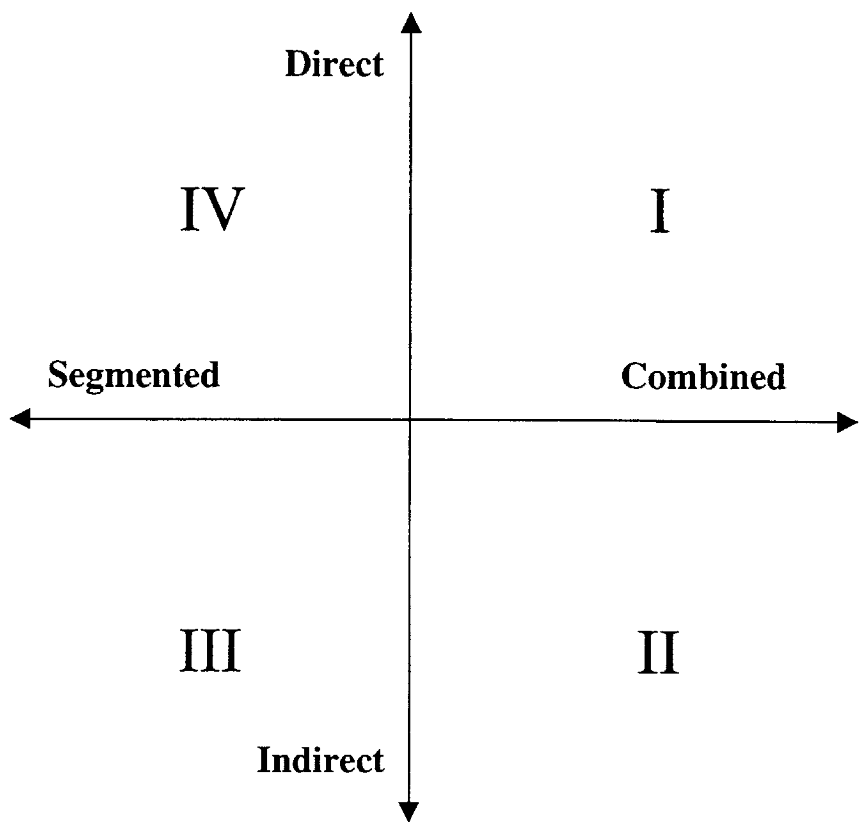

Figure 3-1 Quadrant Analysis

Segmented delivery means that the different lifecycle functions are performed by different participants. Combined delivery means that different lifecycle functions are integrated and performed by one participant. The degree of integration defines the placement of any delivery method on the horizontal axis. Direct financing means that an owner is providing guaranteed financing and no financing responsibility lies with any of the other project participants. Indirect financing means that the owner is not providing the financing for the project, which will instead be generated by user fees and privately raised capital. The degree of financing risk assigned to either party defines the placement of any delivery method on the vertical axis.

Quadrant I represents Combined and Direct delivery methods, and is descriptive of such methods as Super-Turnkey and Design-Build-Operate. Super-Turnkey combines the functions of design and construction with the financing of the project, with the funding coming directly from the owner. Design-Build-Operate (DBO) combines the functions of design and construction with operations, and also leaves the risk of funding directly with the owner. This quadrant allows for an owner to shift some, but not all, of the risks and incentives to the third parties contracting with the owner. Quadrant I methods require a high level of owner competence to deal with the intricacies of each contracting type, due to the risks involved.

Quadrant II represents Combined and Indirect delivery methods, and is typically represented by the Build-Operate-Transfer (BOT) method. This method allows an owner to pass a large share of the risks and incentives to third parties willing to design, construct, operate, and finance a project over a long period of time. This allows an owner to build needed infrastructure assets that may be financially viable on their own without investing large amounts of capital directly into them. Quadrant II methods also require a high level of owner competence to structure a fair and equitable agreement, while mitigating the many risks inherent in such a proposal.

Quadrant III represents Segmented and Indirect delivery methods, but represents no common methods due to its unique nature. Funding from indirect sources like user fees generally indicates a need to reduce costs and assign risk to one party, rendering segmented delivery methods unreasonable. Only environmental remediation projects, such as Superfund, have historically been placed in this quadrant.

Quadrant IV represents Segmented and Direct delivery methods, and includes such common methods as Design-Bid-Build (DBB) or Design-Build (DB), where the functions of financing and operations are separated from the design and construction of a project, and financing is provided directly by an owner. This quadrant is typical of the vast majority of projects in the United States at this time. Financing is provided directly from the owner, and the functions of design and building a project are completely distinct from the function of operations. The risk of financing lies completely with the owner.

This quadrant framework allows a fuller understanding of the factors that influence choices of delivery methods. The point is to view project delivery and finance methods as variables to be managed in the infrastructure development process (Miller 1997).

3.3 Creating Incentive to Consider Lifecycle Costs

Plenty has been written on the relative benefits of each of these delivery methods (Gordon 1994), but their effect on long-term infrastructure management has not been fully addressed. By viewing the delivery method as a variable to be chosen independent of project selection, an owner can weigh each delivery method based on whatever factors may be important in that particular situation. The rest of this chapter will show how integrated delivery methods, typically DBO or BOT, can promote effective infrastructure management.

In choosing an integrated delivery method, the ultimate goal of the owner should be to create incentive among all project participants to consider the lifecycle costs and implications of each of their decisions. This could be true in all choices of delivery method through different strategies, such as partnering or value engineering. But by integrating the lifecycle phases within the delivery methods, incentive is given to consider the entire project's lifecycle.

3.3.1 Integrated Delivery Methods

Integrated Delivery Methods are used to provide integration between some or all of the phases of an infrastructure asset's lifecycle. This will provide incentive to a project's participants to consider the implications of their decisions on all assets and on the entire infrastructure network. Essentially, by integrating any of the lifecycle phases, the owner now has a reason to consider the lifecycle costs of their decisions. It is particularly beneficial if this incentive can be transferred to each participant in each phase of the lifecycle.

Integration of the various lifecycle phases provides collaboration between project participants. For the purpose of infrastructure management, it is almost imperative that the integration not only includes the functions of design and construction, but also operations & maintenance. This will ensure that long-term concerns are addressed in the early stages of a project. The main point becomes that the integration of operations with design/construction gives the strongest incentive to consider lifecycle costs instead of construction costs only. This will lead to better maintained infrastructure and a higher level of service to the public, lower lifecycle costs and longer service lives, and the introduction of better infrastructure management processes. The implicit assumption is that infrastructure performance increases when both lifecycle costs are minimized.

The six delivery methods identified above, with the exception of Design-Bid-Build, integrate some of the infrastructure lifecycle phases. There are numerous advantages and disadvantages of using any of these 'alternative' delivery methods on any given project (Gordon 1994). But these will not be discussed in great detail here. Instead, each will be analyzed for how it creates incentive to consider lifecycle costs in the early stages of any project.

Design-Bid-Build and Design-Build share similar characteristics when considering their lifecycle implications. Both are more concerned with the completion of the construction phase than the entire lifecycle and this affects their results with respect to infrastructure management. By not integrating operations & maintenance with design and construction, the focus of the project shifts to completing the construction, not providing the best service during operations.

Design-Bid-Build (DBB), over the last fifty years, has become the de facto delivery method of choice, primarily for legislatively defined reasons. With federal funding for infrastructure come federal procurement regulations mandating the separation of design and construction (Miller 1997). What this has done is erect an imaginary wall between project participants in the name of 'fairness' and professional integrity, while neglecting the consideration of the entire lifecycle of a project until completion of construction. To its benefit, DBB encourages tried and true solutions that are known to work, but it does not leave the flexibility for innovation.

Design-Build (DB), while gaining popularity in recent years, encounters the same problem as DBB. The entire lifecycle of the project is not addressed with this delivery method. However, increased collaboration between designers and constructors does have other, more subtle, effects on long-term concerns. Projects might be constructed more to the spirit of the design than to the letter of the design, providing structural behavior that is as intended by the designers. But overall, DB provides no explicit reason to consider lifecycle costs or issues.

Design-Build-Operate and Build-Operate-Transfer also share similar characteristics when considering their lifecycle considerations. Both provide incentive for contracted teams to consider the entire infrastructure lifecycle. This incentive comes from the integration of operations & maintenance with design and construction.

Design-Build-Operate (DBO) differs from Build-Operate-Transfer (BOT) only in the source of the funding for the contract. DBO is a directly funded delivery method in which an owner pays directly for the services, while BOT is an indirectly funded delivery method in which the services are generally associated with some cash stream that are borrowed against to provide an initial capital source. Although BOT is typically associated with more risk on the part of the contracting team because of the dependence on indirect financing, both BOT and DBO provide excellent incentive to consider lifecycle costs and infrastructure management processes by tying infrastructure performance to profit, if competitively awarded.

3.4 Creating Incentive for DBB and DB to Consider Lifecycle Costs

Because DBB and DB don't have explicit reasons to consider lifecycle costs, an owner must be knowledgeable and skillful enough to create these incentives. Several methods are indicated here:

- **Lifecycle Bidding for all Projects.**
  This practice, though not exact and generally more expensive up-front, would enable designers and constructors to make decisions based on a long-term basis, and could result in the use of better materials and technologies from the outset of a project. One drawback of this suggestion is the imperfect identification of future costs, particularly for new methods and materials.

- **Investing Operations & Maintenance Funds at the Time of Construction.**
  For every unit of infrastructure (SF of deck, LF of rail, etc.) a lump-sum amount equal to the lifecycle maintenance unit costs of the asset would have to be allocated at the time of construction. This change of behavior, though painful at first, would ensure that funds for proper operations & maintenance are available.

- **Strong/Knowledgeable Owner Involvement.**
  Competent ownership during the design and construction stage of a project will allow an owner to get what they want, or at least what they are willing to pay for, with an eye on the long-term costs of the decisions they make.

Ultimately, creating incentive to consider lifecycle costs might result in higher initial costs, but minimum lifecycle costs are expected. This is the goal of these strategies.

3.4.1 Political Implications

It is difficult to enable these types of actions for the sole reason that lifecycle planning typically costs more in the short-term than in the long-term and elected officials and administrators are concerned with short-term budget goals and re-election. Because the benefits of lifecycle planning are not noticeable for decades, long after an official leaves office, it is a hard political decision to spend more money now to spend less money later. Results are not easily apparent and are not useful in campaigns. This is a tragic truth to American politics. As a result, our infrastructure problems are not easily rectified without strong political will.

3.5 Keeping Incentive for DBO and BOT

Although DBO and BOT have built-in incentives to consider lifecycle costs, strong owner management is needed early in the project to ensure that these incentives are best utilized. Of prime importance is the initial planning of the procurement strategy and the use of competitive bidding. By setting up the process correctly according to preset procurement principles, the maximum benefit can be gained from these delivery methods with respect to providing incentives to ensure the consideration of lifecycle costs and infrastructure management processes.

The need to set the process up correctly has led to some research into the methods by which infrastructure procurement strategies fail. Miller's infrastructure procurement metrics can help to analyze the contracting strategy and planning process to determine how functional and useful the procurement is. These procurement strategy metrics are:

- **Scope**
  In order for a competitive bid to work, bidders must have a clear sense as to the scope of work that they are bidding on.

- **Competition**
  Projects should not be awarded to bidders that did not compete for a project. This ensures a market evaluation of project risks and revenues. Sole-source procurements should be avoided.

- **Fair Treatment of Competitors**
  All competitors should feel that the procurement went smoothly, and no hint of improper award or favoritism should be given.

- **Transparency**
  The rules of the procurement should be consistent throughout the entire process, so that bidders are aware of all criteria from the start.

- **Independent Engineering Check**
  An independent evaluation of technology, means, and methods will ensure the safety and viability of the project.

- **Open to Technological Change**
  Procurements should be flexible with respect to the technology used. This allows innovation to be introduced.

- **Sound Lifecycle Financial Analysis**
  The foundation of project analysis should be lifecycle costs to ensure that the implications of all decisions are weighed over the entire life span of the project.

- **Alternatives Analysis**
  An evaluation of a variety of solutions will allow the best method to be chosen.

- **Infrastructure Network Consideration**
  The effect of all choices and decisions should be measured not only against its effects on the project, but on the entire infrastructure network.

Each of these metrics has an effect on infrastructure management. Anything that can force an owner to view a project with an eye towards the future or on the entire asset network is useful. In many cases, an infrastructure management failure can be traced back to a procurement failure. Considering these metrics prior to establishing a procurement strategy can help to avoid potential failures (Miller 1998).

3.6 Examples of Delivery Method Choices on Infrastructure Management

This section will examine four cases of infrastructure projects where the choice of delivery method affected the infrastructure management of that project. These four projects are: the Interstate Highway System; the Construction Grants Program; the Northumberland Bridge; and the New Jersey Light Rail system.

3.6.1 Interstate Highway System

The Interstate Highway Act of 1956 authorized the construction of a system of national defense highways, sometimes called the Eisenhower Interstate System. Under this act of congress, the federal government mandated several things. First, the alignment of the system was subject to congressional approval. This ultimately led to an alignment that goes through 406 of the 435 congressional districts. Second, the federal government agreed to provide 90% of the funding for construction, and the states were expected to provide the additional 10%. Seeing this great opportunity to stimulate economic development, increase personal mobility, and create jobs, this facet of the legislation created an overwhelming level of support among contractors, truckers, engineers, and automobile advocacy groups. But in order to receive these federal grant monies, federal procurement regulations were enforced. This led to a very segmented delivery method whereby an alignment was handed down by Congress, engineers designed the highways, and the lowest bidder built them. This delivery method is indicative of a quadrant IV procurement (Miller 1997).

Approximately $40 billion was spent on the construction of this highway system through 1990. This includes over 41,000 miles of roads primarily paid for by taxes on gasoline and designed for a short twenty-year life (Miller 1997). The near-sighted federal policy of providing 90% of the construction cost and nothing for maintenance costs has encouraged overbuilding, leading to grossly inadequate levels of funding for lifecycle maintenance needs. This fact became apparent during the 1970's energy crises. Fuel conservation coupled with more fuel-efficient engines caused federal gasoline revenues to drop drastically, just about the same time that these roads needed major maintenance and repair. States didn't have the money to fix the roads, having spent their money on new construction. In 1976, Congress finally was finally forced to earmark money for maintenance (Goddard 1994).

As seen, this reactive approach to infrastructure management did not yield optimum lifecycle costs. Even now, the interstate highways are in poor condition, having deferred their maintenance due to funding shortfalls. The choice of delivery method caused some, if not most, of this problem. The lack of lifecycle planning (i.e. no incentive to consider lifecycle costs during design and construction) led the government to pursue the 'heroic' option of providing thousands of miles of interstate highways, while neglecting the inevitable maintenance costs.

3.6.2 Construction Grants Program

The Federal Water Pollution Control Act of 1972, which created the Construction Grants Program, provided $60 billion in federal matching grants for the design and construction of municipal wastewater treatment plants, lateral and interceptor lines, and pumping stations. This grants program was very similar to the interstate highway procurement. This time, the federal government provided 75% of total costs, and states typically provided another 15%, leaving a municipality to provide only the last 10% of total costs of obtaining a brand new water treatment facility. Again, federal funding mandated federal procurement regulations, and a quadrant IV procurement was used, which separated the design and the construction (Miller 1997).

This program was intended to bring all municipalities up to the mandated levels of secondary water treatment. Sadly, in 1992, the Environmental Protection Agency (EPA) estimated that this initial grant program had not been enough, and another $131.7 billion would be needed over the next twenty years for all municipalities to meet federal water quality standards. This estimate did not include operations & maintenance of the new facilities.

As a result of this quadrant IV procurement that neglected lifecycle concerns, overbuilding again became a problem, as it had with the interstate highway system. Localities were allowed to build treatment capacities well past their foreseeable needs, wasting grant money, and increasing their own maintenance costs. Again, not considering the full lifecycle costs of these projects led to under-funded maintenance and even led to increased construction costs.

3.6.3 Northumberland Bridge

The Northumberland Bridge, also called the Confederation Bridge, connects Prince Edward Island with mainland Canada north of Nova Scotia. This 8-mile, multi-span bridge is a technical marvel. Built to withstand 100 years of brutal Canadian ice and wind while spanning a major shipping lane, this bridge is a lasting testament to the procurement used to deliver it. This may seem a little premature, since the bridge was completed in the spring of 1997, but the procurement seems destined to stand up to the scrutiny of time.

This procurement process has been billed as a BOT. One contracting team was competitively selected to provide the design, construction, and operation of the bridge for 35 years. The contractor agreed to assume all risk in relation to the operation and maintenance of the bridge throughout the operating period. In maintaining the bridge, the contractor agreed to perform all maintenance necessary to ensure that the design life of 100 years would be reached. Financing was provided in the form of an annual subsidy equal to previous ferry subsidies, and tolls would provide additional funding. This procurement included many salient features and I will only discuss those that affect infrastructure management.

As part of the bridge operating agreement between the Canadian government and the contracting team, a long-term maintenance plan, outlining all maintenance practices and procedures, was required to be submitted to and approved by the government. This plan includes a detailed strategy for meeting the overall maintenance goals. This includes forecasted capital and operating budgets, inspection procedures, repair procedures for all components, standards for seasonal maintenance, and identification of all operational activities affecting maintenance (PWGSC 1993).

This preplanning was intended to ensure that the bridge functions effectively for its entire design life. By attempting to predict the maintenance that would be necessary to keep the bridge in optimum condition, the contracting team was forced to consider the lifecycle implications of their planning, design, and construction decisions. This leads to a higher level of service for the bridge, and a minimization of lifecycle costs.

3.6.4 New Jersey Transit Light Rail

As part of a similar federal grant program that is funding Tren Urbano (See chapter 6), New Jersey Transit is constructing a $1.1 billion light rail system. A 9.5-mile alignment will carry commuters from Bayonne to Hoboken with 16 stations. This project is a Design-Build-Operate (DBO) project with a 15-year operation period. The system is supposed to begin revenue service in March 2000.

There was originally concern within New Jersey Transit (NJT) that a private DBO contractor wouldn't take ownership-care of the system, instead maintaining the system on a 15-year hand-off curve basis. This fear has been allayed however, since NJT realized that ultimately, the contractor is responsible for operating the system no matter how they construct it. As a result, NJT has noticed that the contractor is "paying much more attention than they otherwise would because they have to run it." And this attention is not only focused on the design and constuction of the civil infrastructure elements, but also to vehicles and systems.

This 15-year operations period appears to have given the contractor a lot of incentive to get the design and construction right. They recognize the responsibility that operations & maintenance entails and the lengthy operations period covers several cycles of routine maintenance and repairs. The fact that they are doing all of this on a fixed price gives them an incredible incentive to plan for the entire lifecycle of the system in order to manage their costs. As with the Northumberland Bridge, it is too soon to know whether this procurement will be successful. But due to the integration of design/construction with operations & maintenance, the long-term viability of the system has been addressed, and will hopefully be ensured (Duffy 1998).

3.7 Summary

This chapter defined the concept of integrated delivery methods and introduced the reader to various delivery methods that integrate a project's lifecycle. Integrating the various lifecycle phases creates incentive for all project participants to consider the lifecycle costs and implications of their decisions and actions. The four projects given here showed how the relationship of the operations & maintenance phase with design and construction affected each project. While these projects are difficult to compare head-to-head for reasons such as project size, age, and asset types, several broad lessons can be learned. The primary lesson to be learned from the interstate highway system and the construction grants program is that a project's entire lifecycle must be addressed during design and construction phases. This will avoid the problems of overbuilding and limited maintenance funds that occurred.

Likewise, it is seen in the case of the Northumberland Bridge and the New Jersey Transit Light Rail projects, that owners and project participants are willing and able to consider the entire lifecycle during design and construction, so long as the right incentive is given to do so. The need to attract private capital and shift risk to private sector participants forces owners to establish a clear scope of responsibility on which to competitively award projects.

Every procurement is different, and requires a unique delivery method. This chapter attempted to show how integrating the different lifecycle phases of a project can achieve long-term viability of a project's infrastructure assets. If this is a goal of the procurement, then integrated delivery method can provide this incentive to all participants to consider the entire lifecycle.

4 Infrastructure Management Systems

4.1 General Review

There is a need to derive the maximum possible benefits from every dollar spent on transit and infrastructure in general. Briefly described in chapter 2 were two methods for doing this. Integrated Delivery Methods and Infrastructure Management Systems, which both rely on lifecycle planning, are two ways in which owners have chosen to manage their infrastructure assets. This chapter will investigate how infrastructure management systems are utilized in the infrastructure management process.

4.2 History of Infrastructure Management Systems

To understand infrastructure management systems and how they function, it is first necessary to examine the historical development of such systems, and the evolution of the technologies used by infrastructure management systems.

The 1960's saw computer technology fast becoming affordable and accessible to all industries. Owners of infrastructure assets saw the benefits of being able to keep an inventory and monitor the performance of their assets. But the costs of doing this were prohibitive to all but the largest owners. Consequently, the first major development of a computerized management system was for pavement.

4.2.1 Pavement Management Systems

These pavement management systems (PMS) were used to monitor pavement condition and deterioration, and to allow for more efficient maintenance planning. The objective of these systems is to maintain the pavement network in its most desirable condition considering the constraints imposed by budgetary concerns and to allow an owner to provide network-level consistency in maintenance to protect the owner's pavement investment. A cost-benefit evaluation of network level pavement management was done to assess the quantitative benefits of installing a PMS. It indicated that actual monetary benefits are difficult to estimate. But if even a small percentage of cost savings found after implementing a PMS are due to the PMS, the benefits far outweigh the costs (Falls 1996). Consequently, most state and local agencies are currently utilizing pavement management systems.

4.2.2 Bridge Management Systems

The widespread use of pavement management systems led to the development of similar bridge management systems (BMS) for the nation's bridges. The collapse in December 1967 of the Silver Bridge in Point Pleasant, Ohio, which killed scores of motorists, awakened many in the transportation industry to the need for systematic inspection of the nation's bridges. The resultant National Bridge Inspection Standards (NBIS) program of 1968 resulted in a huge amount of data on the nation's federal bridges available for analysis. NBIS was expanded in 1978 to include all bridges. From this, it was determined that 400,000 of the nation's 570,000 bridges were more than 50 years old and approximately 40% of all bridges were found to be either structurally deficient or functionally obsolete. Additionally, these figures would only get worse as more time passed and since the funding did not exist to fully fix these problems. Clearly, a systematic method was needed to determine how to best allocate funds so as to fix the most pressing problems. The first bridge management systems were paper inspection systems that required handwritten reports to document every inspection (Wells 1995).

Duplication of efforts to develop a computerized system were performed in the 1970's all across the country, and most amounted simply to database or spreadsheet-type of programs that listed inventory information and attempted to identify bridges for maintenance and rehabilitation. In 1985, the federal government entered the picture with the initiation of NCHRP (National Cooperative Highway Research Program) Project 12-28(2), Bridge Management Systems. The goal of this project was to develop a model form of effective bridge management. The FHWA also began similar efforts with the development of Pontis, a network-level bridge management system, in 1986.

Finally, in 1991, the Intermodal Surface Transportation Efficiency Act (ISTEA) mandated the use of, among others, bridge management systems and transit management systems for those agencies receiving federal funding. Though the mandate was later rescinded, many owners opted to continue their development work in this field. There are currently two federally initiated bridge management systems on the market, Pontis and Bridgit, as well as several in-house developments being used across the country.

4.2.2.1 Pontis and Bridgit

The ISTEA mandate in 1991 for bridge management systems caused increased interest in the development of these systems. The FHWA had previously initiated Demonstration Project No. 71 in October 1986. In September 1989, a contract with two private companies to develop a functioning BMS and to beta test the product with thirteen state DOT's and the city of San Jose was initiated. This development, which produced Pontis, was completed in December 1992 and coincided well with the ISTEA mandate. At this point, a decision was made to transfer responsibility for Pontis from the FHWA to AASHTO. Currently, Pontis is being used by nearly forty state DOT's and several foreign governments (USDOT 1989).

The strengths of Pontis are that it supports the entire bridge management cycle, allowing for user customization in nearly every aspect of its operation. Promotional material for Pontis states that "the system stores bridge inventories and records inspection data. Once inspection data have been entered, Pontis can be used for maintenance tracking and federal reporting. Pontis integrates the objectives of public safety and risk reduction, user convenience, and preservation of investment to produce budgetary, maintenance, and program policies. Additionally, it provides a systematic procedure for the allocation of resources to the preservation and improvement of the bridges in the network. Pontis accomplishes this by considering both the costs and benefits of maintenance policies versus investments in improvements and replacements" (CSI 1998). Specifically, Pontis keeps all network and industry data in a relational database, which when combined with the inspection data, are used to model lifecycle needs to assist in the identification of future projects.

Bridgit can trace its development along similar lines as Pontis. Bridgit is a microcomputer-based bridge management system developed under NCHRP Project 12-28(2)A to assist state and local transportation officials meet the requirements of the FHWA. Bridgit allows agencies to store and modify inventory, inspection, and maintenance information for bridges and culverts. Its capabilities are very similar to and slightly more intuitive than Pontis, though the level of analysis is distinctly less sophisticated. System factors also limit the number of bridges that can be practically managed by Bridgit to around 5000, well below the number of bridges that most large states own (Lipkus 1998).

4.2.2.2 Georgia DOT – Bridge Information Management System

The Georgia Department of Transportation (GADOT) has just recently implemented a modern bridge management system (BIMS), based around their system of biennial inspections. This system records bridge inventory, condition rating data, and other bridge related data items. This system is excellent for compiling data on its bridges by allowing for the storage of design documents, photographs, as-built drawings, and past inspection reports, and this information is quite useful when planning future inspections or in emergency situations where accurate information is needed quickly. However, its weakness lies in its inability to allow any type of historical deterioration modeling due to the way in which inspection records and past information are kept. All records have been entered into a database, but only current condition and performance data are kept, and old data is dumped to a visual back-up system. The result is that there is no capability to analyze network-level trends in deterioration or performance over time (Summers 1998).

4.2.3 Transit Management Systems

Work on transit management systems was never as systematic as with pavement or bridge management systems. This is primarily due to the unique nature of each transit system and the assets owned by each. Transit systems have a much wider variety of infrastructure assets when compared to bridge or pavement managers. For this reason, development of transit management systems has taken longer and has seen more varied approaches. An additional reason for the difference is the size and geographic spread of infrastructure networks owned. A typical state department of transportation might own anywhere between 10,000 and 50,000 bridges in an entire state, while a transit agency's assets are generally on a smaller scale and are located in one city or region. The benefits gained from implementing a management system might not be as apparent in transit. Section 4.3 will provide more detailed information on the types of systems being used in transit systems across the country.

4.2.4 Integrated Infrastructure Management Systems

Though much work has been performed on the development and implementation of these management systems for pavement, bridges, transit, and other infrastructure subsystems, work has not truly focused on integrating these various subsystems, including roads, bridges, utilities, transit, and water/wastewater into an integrated infrastructure management system until recently.

Predictions were made that these subsystems would eventually lead to integrated management systems, but this has not yet happened. A great deal of work has started to attack this disparity. The similarities of these subsystems have been recognized, and efforts to begin to make these systems compatible have been discussed, but the problems of doing so are still prohibitive (McNeil 1992, Smith 1992).

Data management, and more specifically, location referencing, is cited as the primary problem in developing an integrated management system for infrastructure, because of the different referencing systems and subsystem specific data needs of each type of infrastructure. These systems have been developed according to each infrastructure's needs and will be difficult to reconcile between infrastructure types. Additionally, benefit calculations are consistent within each subsystem, but may not be a useful basis of comparison between infrastructure types due to the perceived importance of each. Given these relative benefits, the issues of capital investment requirements, safety implications, and criticality of service have been proposed to give these benefits a comparative basis. This will help with data management, but the real problem in these integrated systems will be understanding how the microscopic aspects of each infrastructure interact with each other, and determining how these interactions affect the macroscopic aspects of the relationships of each infrastructure type (Lee 1995).

The work of Lemer and Wright to build a truly integrated infrastructure management system, as a result of suggestions from the City of Indianapolis, is the first of its kind. This ambitious project is being developed as a management and decision-support system that will "provide responsible managers with meaningful information on the status and performance of their system and means for exploring how future demands and management policies may influence performance." This integrated infrastructure management system is envisioned as a computer-based management tool that will "apply advanced information collection and management technologies to provide more efficient, accurate, and effective bases for making decisions about infrastructure." This system will combine inventory, condition assessment, predictive modeling, scenario development and user-friendly information-access capabilities in a top-down scheme, and coordinate with and draw upon the more detailed systems of individual infrastructure types. If developed as promised, this system promises to be the most integrated infrastructure management system currently in the industry. As proposed however, it seems to downplay the role of engineers in the decision-making process, possibly due to its top-down approach to infrastructure management.

Additionally, this system only implicitly accounts for alternative delivery methods in its capital budgeting process.

The future of these systems remains to be seen. Advances in automation and information technology continually push the limits of what is possible, and infrastructure managers would be wise to keep on top of all the latest developments. Ideally, the envisioned infrastructure management system of the future would provide everyone with all of the information that they need. This would include system engineers, operators, managers, public officials, and even the public at-large. This information would be tailored and specific to each participant's needs.

Specifically, these systems would allow access to a map of the specified region, and provide information regarding the condition and performance of the infrastructure network, individual assets, or relationships between those assets. All pertinent data, including design documents, as-built drawings, photographs, inspection reports, maintenance records, planning projections, and spending histories would be available at the click of a button.

Analyses of budget and policy effects on future infrastructure performance and needs could be played with to view results of different actions, including funding levels, policies, or delivery methods. These analyses would be based upon historical and projected cost data of providing infrastructure services, and would monitor and adjust current projections based on this cost data.

These systems will begin to develop better reporting tools that can help to support decisions for future planning of projects. Reporting will be customized to the user in order to support the entire infrastructure lifecycle. The cost data contained in these systems becomes quite useful when attempting to pursue alternative delivery methods with future projects. Such systems are not far away.

4.3 Infrastructure Management Survey

The attached survey (See Appendix B) was sent to 15 major transit agencies in North America. The stated intent of the survey was to "capture the policies and practices of the rail transit agency with respect to infrastructure inspection and infrastructure management."

All of the surveys were sent to executives, presidents, or general managers of the respective agencies. It was assumed that by targeting such high-level officials for the mailing, the responsibility of completing the survey would be delegated to the most appropriate department or person in the organization. This would lend credence to the results and allow for a credible analysis.

This survey was written to determine the practices, opinions, and sophistication of the agencies with respect to infrastructure management. It included questions of general demographics, infrastructure inventory, inspection practices, and infrastructure management policies and systems. The prime goal was to determine the current practices or future plans for infrastructure management in their transit agencies. Below is the list of North American cities whose transit agencies received a survey.

Region or City	Transit Agency Acronym
Atlanta	MARTA
Baltimore	BaltMTA
Boston	MBTA
Chicago	CTA
Cleveland	GCRTA
Los Angeles	LACMTA
Miami	MDTA
New York City	NYCTA
Philadelphia	SEPTA
San Francisco	BART
Washington DC	WMATA
Montreal, Quebec	STCUM
Toronto, Ontario	TTC
Dallas	DART
St. Louis	MetroLink

Figure 4-1 Transit Agencies Targeted for Survey

Of these fifteen agencies, eight responses have been received. These eight are MARTA, BaltMTA, NYCTA, MBTA, MDTA, DART, BART, and STCUM. Respondents from WMATA, CTA, GCRTA and TTC have indicated that they will not be participating in the survey due to lack of available resources to complete the survey. SEPTA, MetroLink, and LACMTA have not responded. Five surveys were also sent to agencies in South America (Lima, Caracas, Santiago, Buenos Aires, and Medellin), but none have responded.

4.3.1 Survey and Correspondence Results - General

Of the eight surveys that have been received, the quality of responses has varied significantly. Some agencies have provided the bare essentials needed to complete the survey and some have gone out of their way to assist this research by providing detailed information and assorted extras, making detailed comparisons difficult. Obviously, the quality of each agency's response tends to bias the analysis in that direction, but this is reasonable, since the agencies were responsible for the quality of the completed survey and this could indicate the degree of sophistication of each agency.

4.3.1.1 Demographics

Several general trends were noticed in the responses to the survey and will be discussed below.

Structurally, these systems were quite varied, with many types of materials being used in many different environments. Those that answered indicated that superstructure elements were made of Reinforced Concrete, Prestressed Concrete, Post-tensioned Concrete, and Steel, while tunnels (both Cut & Cover and Drilled) used Reinforced Concrete, Prestressed Concrete, Steel, Cast Iron, and Rock. Additionally, track ties were indicated as made of both timber and concrete. The track was typical steel track for all except for STCUM, which uses rubber tires running in concrete tunnels, and electrification was provided by third rail or catenary systems.

Agency	Title of Respondent	Track Mileage	Number of Stations	Age
MARTA	Vice President of Facilities Maintenance	120	36	19
BaltMTA	Manager, Facilities Engineering Division	45	46	15
MBTA	General Manager	65.8	129	100
DART	Senior Manager of Technical Services Engineering	40	20	2
MDTA	Assistant Director of Rail Operations	44	21	15
STCUM	Project Director	40.4	65	31
NYCTA	Chief of Operations, Subway Maintenance-of-Way	656	469	110
BART	Manager, Track and Structures	227.6	39	26

Figure 4-2 Demographic Results of Survey

4.3.1.2 Inspection

All respondents indicated that a systematic series of track, structural, and system inspections were being performed, based upon industry standards and performed by personnel with both special training and experience. In the case of MARTA, their structural inspections began seven years after the start of revenue service, while DART began with their structural inspections immediately after construction of the system. Others respondents were not as specific, but it is reasonable to believe that track and system inspections have been part of transit agency's priorities for longer than structural inspections. This is due in part to the necessity of keeping track and system infrastructure in top condition for short-term safety and efficiency reasons, and for the long-term deterioration behavior of structural components, which is not noticed except when measured in years or even decades. *Figure 4-3* outlines the inspection responses from each agency.

	MARTA	BaltMTA	MBTA	DART	MDTA	STCUM	NYCTA	BART
Structural Intervals (years)								
Elevated Guideways	2	2	-	2	2	N/A	1	2
Tunnels	2	5	-	2	-	1	1	2
Stations	2	5	-	1	-	3	1	2
Switches Intervals (months)								
Visual Inspections	1	-	2	1	-	3	-	¼
Other Inspections Indicated?	No	No	Yes	No	No	No	No	Yes
Track Intervals (weeks)								
Visual Inspections	½	1	1/3	1	2	1	½	1
Other Inspections Indicated?	Yes	No	No	No	Yes	No	Yes	Yes
System Inspections	Industry Standard	As Needed	-	Varies	Varies	Varies	-	Every month

Figure 4-3 Inspection Practices

4.3.1.3 Management Systems

Most respondents indicated that they utilize some sort of infrastructure management system, typically a maintenance management system. These systems are developed in-house and have mostly been indicated to be spreadsheet-based management systems that are maintained and used by separate departments, not the entire agency. Consequently, these systems do not have the capability to be integrated into a complete management system.

Although MDTA was unsure of what an infrastructure management system was, most other respondents understood the benefits of what a system could do for their agency. However, very few could comment on the costs associated with either their own management system efforts or any potential development projects. This is a very telling fact about the state of infrastructure management. If these agencies are not able to identify the costs associated with their own internal processes, then this is an indication that these agencies don't make rational decisions based on cost-benefit analyses or lifecycle costs. BART indicated that an infrastructure management system was prohibitively expensive.

No respondent that understood the benefits of an infrastructure management system disagreed that implementation of such a system, and it's associated inspection and maintenance efforts, concurrently with construction of new infrastructure assets was a good idea.

Nearly all respondents indicated that their own efforts at infrastructure management were not adequate and seemed to think that their own system or process needed to be improved, and several are currently investigating different options to improve their own efforts. MARTA and MBTA are about to issue RFP's for several different management systems, and these will described below. *Figure 4-4* shows the survey responses with respect to infrastructure management systems.

	MARTA	BaltMTA	MBTA	DART	MDTA	STCUM	NYCTA	BART
IMS Indicated	Yes	Yes	No	Yes	No	Yes	Yes	Yes
Computerized	Yes	Yes		Yes		No	Yes	Yes
Integrated or Departmental	Int.	Dept.		Dept.		Dept.	Dept.	Dept.
1. Structural Inventory	X	X		X		X	X	X
2. Track Inventory	X	X		X		X	X	X
3. Systems Inventory	X			X		X		X
4. Standardization	X			X		X	X	X
5. Inspection Planning	X	X				X	X	
6. Records Archival	X	X		X		X	X	X
7. Maintenance Options		X		X			X	X
8. Cost Estimation of Options	X	X		X			X	
9. Modeling of Deterioration	X							X
10. Funding Optimization	X	X					X	
11. Network-Level Decisions	X							

Figure 4-4 Infrastructure Management System (IMS) functions by Agency

4.3.2 Survey and Correspondence Results - Specific

In addition to the general results, the specific survey results and other correspondence allow for a description of the types of infrastructure management or other systems that are being used around the country. *Figure 4-5* presents all qualitative survey responses. These comments, and other data obtained both from the survey and additional correspondence helped to form the basis of the summaries presented below.

Describe your agency's use of your infrastructure management system and its importance to the departments that use it.	MARTA: Used to evaluate maintenance activities, allocate and reallocate resources, measure and evaluate process change for improvement, understand the cost of business processes, evaluate categories and classification of work for comparison to industry standards. "The system can really identify opportunities for improvement and areas of wasted effort." BaltMTA: Used for biennial inspection of structures to recommend repairs and forecast needs for inspection and rehabilitation budget. MBTA: No comment. DART: Used "for on-going avoidance by early identification and detection by weekly preventive maintenance inspection of ROW. Current system is in the process of being inventoried and baselined." MDTA: "N/A" STCUM: "N/A" NYCTA: "Each major infrastructure division (Track, Structures, Line Equipment, and Signals) maintains their own system." Mostly databases of deficiencies, defects, and historical maintenance, repair, and replacement actions. BART: "Each section or division maintains records separately. These records are essential for long term maintenance planning and budgeting."
Describe the costs associated with implementing/maintaining your infrastructure management system.	MARTA: Unknown. BaltMTA: "Structural Inspection: $400,000/year; Structural Repairs: $200,000/year." MBTA: No comment. DART: Unspecified amount associated with internally developing the database. MDTA: "N/A" STCUM: "N/A" NYCTA: "N/A" BART: "Not Applicable"
Describe the benefits associated with implementing/maintaining your infrastructure management system.	MARTA: "Benefits are associated with the current use categories and are self-explanatory." BaltMTA: "Programming Capital Needs for System Preservation." MBTA: No comment. DART: Cited are benefits in cost avoidance, service down time, and safety. MDTA: "N/A"

	STCUM: "N/A" NYCTA: "Production Tracking, Planning for Rehabilitation Projects, Cost Analysis, Resource Allocation Analysis, Certification of Inspection, Prioritizing of Defects, Maintenance Trend Analysis." BART: "N/A"
Describe your agency's history with infrastructure management systems.	MARTA: Early attempts with spreadsheet-type systems that were not very useful. This current system is 6 years old and in continuous evolution. Plans are in place to advance the system to a newer technology. BaltMTA: First agency to initiate structural inspection program in 1986, and used simple database inventory. Recently added photo-based database. MBTA: No comment. DART: History of managing assets with Maintenance Document Control System. "This system is developed to provide a level of configuration control. It does not maintain day-to-day maintenance/inspection activities. It has been recently expanded to provide for bridge/tunnel inventory/inspection." MDTA: "No History" STCUM: Began inspection program in early 90's that resulted in renovation cost model and ten year capital plan of $15 Million/year. Also began periodic preventive maintenance program. NYCTA: Used "in one form or another since the beginning of the system." Originally used to track inspection and maintenance cycles and indicate areas of high maintenance. Mostly defect reporting system using paper reports and index cards. In the early 70's this paper system was transferred to a computer system, with each division taking their own direction as to the type and extent of their database. BART: Early attempts failed due to "insufficient funding to implement a system; no empowered organization placed in charge of the system; insufficient funding/staff to maintain system; piecemeal approaches to implementing a system."
Please give your opinion on the usefulness of using an infrastructure management system in rail transit.	MARTA: Effective management "of complex maintenance systems will require some sort of automation." Development must be done well in advance with professionals involved in the business of maintenance management, not just information technology. Development in conjunction with industry standards will lead to "excellence in service and reliability of your systems." BaltMTA: Structural inspection program provides a tool to determine structural defects and enables timely repairs. MBTA: No comment. DART: "Integrated systems can be extremely useful as long as systems are not duplicated. New and old systems must be compatible and user-friendly. Most systems that do all can be costly and may be better served if specific to a set requirement." MDTA: "N/A" STCUM: "N/A" NYCTA: This would be a "useful tool for developing the Capital

	Program Projects." "Any system requires the use of an infrastructure management system. The only variable would be the scope of the records system. A larger rapid transit system would require a larger and more all-encompassing system." BART: "Infrastructure management systems, if properly implemented and used, is an irreplaceable function for maintenance." Benefits include: Historical information that aids in forecasting future maintenance needs; Information for planning and costing major repairs; Forecasting major capital repairs and renovations; Immediate access to information for planning maintenance; Information required for realistic budgets.
Please give your opinion on the usefulness of implementing an infrastructure management system directly after construction of a rail transit system.	MARTA: "I would recommend development of the management system in conjunction with the development of the transit system." This would save time in loading initial data, prevent frustrations of staff that want to focus on maintenance, and will ensure a maintenance history for the system. BaltMTA: "Computerized inventory database should be initiated immediately after construction is completed to provide a baseline for periodic inspection. This also helps in providing information in design deficiency or defects during construction." MBTA: No comment. DART: "When effectively implemented, a system to maintain system configuration will reduce costs by controlling assets, managing inspections, and reducing risks through cost avoidance." MDTA: "Probably Very Useful" STCUM: "This is the best way to follow the deterioration. A fund allocation based on the renewal cost and the life expectancy of the components will ease the financing research at the end of the life of the components." BART: "Any system, regardless of age, should implement an infrastructure management system. Inspection, maintenance, and repair records should be kept from the system's start-up."
Other comments.	MBTA: There is no computerized infrastructure management system. All inspections are done visually, defects are tracked on paper and reported to supervisors, who schedule maintenance and prioritize work needs. MDTA: "Not familiar with an infrastructure management system." STCUM: "The infrastructure management system is under construction." BART: "The cost of implementing an Infrastructure Management System is too prohibitive."

Figure 4-5 Qualitative Answers to Survey Questions

4.3.2.1 Atlanta, Georgia – Metropolitan Atlanta Rapid Transit Authority (MARTA)

In recent years, MARTA has developed a strong maintenance management system that also enables some network planning capabilities. This system was developed by Indus International. Their transit system was originally built in 1979, and though regular structural inspections were not done until 1986, it was clear through the responses of the survey that MARTA has made infrastructure management a priority within their organization over the last decade. Prior to the implementation of their infrastructure management practices, 56% of the maintenance performed was reactive, whereas now only 3.7% of their maintenance is reactive.

MARTA's system is based within their Facilities Maintenance Department and is used to evaluate maintenance activities, allocate resources, and identify opportunities for improvement. The actual tasks performed by the system include an automated relational database of structures, track, and systems, as well as general inspection planning, inspection/testing reports archival, and cost estimation of maintenance options based upon prior work performed. This system is automated to generate work orders, priorities of work, and classification of work. It does not, however, perform any network-level optimization or modeling of deterioration rates.

It is the feeling of MARTA that effective and efficient management of complex maintenance systems will require some sort of automation. This automation must not be introduced just by information technology personnel, but with the assistance of the professionals who will use the systems. MARTA recognizes the benefit of beginning this effort by the start of revenue service, as benefits include having a maintenance and cost history, and being able to benchmark future actions. MARTA recommends this based on their own growing pains related to implementation of the system they now are using.

MARTA is planning on issuing an RFP soon for a demonstration inventory and inspection database system. This system is intended to be a Graphical Information System (GIS) with links to all proposed asset data. The RFP indicates that historical information will not be kept in a format useful for modeling or trend tracking, however. The system is intended to have a maintenance forecasting capability based upon condition comparisons between inspections and professional judgement (Carroll 1998).

4.3.2.2 Baltimore, Maryland – Baltimore Mass Transit Authority (BaltMTA)

The Baltimore MTA claims to have been the first transit agency to initiate a comprehensive structural inspection system in 1986, which is modeled after the biennial inspections of highway bridges. With the help of Gannett/Fleming, the Baltimore MTA has developed a bridge management system which allows them to identify the funding each of its three lines (Freight, Metro, and Light-Rail) would get for bridge maintenance and repair. Along with a program of biennial inspections, an asset management database was developed that utilizes graphical information system technology to allow for user-friendly access to inspection findings, condition and load ratings, maintenance needs, and photographs. This information is then used to determine future deterioration. This system then allows the data to be used to make intelligent decisions for allocation of funds to maintain capital assets (Barrett 1997). Additionally, hand-held computers are used to assist in field inspections by allowing inspectors to input their findings directly into the management software (Zarembski 1997).

This system is housed in the facilities engineering division, which performs inspection and repairs, and recommends needed capital funds and repair programs for system preservation. The Baltimore MTA claims that their inspection program provides a method to track defects and perform timely repairs. This system maintains an inventory of track and structures, and archives inspection and maintenance history. While no modeling of deterioration rates is done, optimization of limited fund allocations allows the Baltimore MTA to make maintenance and repair recommendations.

It is unclear whether this system is as comprehensive as they claim it is, and no mention of any type of signal or communications system inventory is made. This appears to indicate that the Baltimore MTA is doing a good job at managing their track and structures through this system, but have not integrated their entire infrastructure network in this process (Sharma 1998).

4.3.2.3 Boston, Massachusetts – Massachusetts Bay Transportation Authority (MBTA)

Based upon the survey, the MBTA uses no type of computerized infrastructure management system. "The line supervisor, section foreman, and system repairman are the last line of defense for ensuring a safe, reliable system." Indeed, they are the only line of defense. These maintenance personnel are responsible for all track inspections and preventive maintenance, such as tightening bolts, adjusting shims, filling and adjusting track lubricators, and lubricating and adjusting track switches and castings. Problems are reported up a paper chain through the command hierarchy and dealt with accordingly.

There was no mention in the survey of structural inspections, though other sources were found which indicated that the MBTA does indeed operate a bridge management system. This lack of understanding within the organization is a telling sign that not all involved personnel are aware of the infrastructure management process.

Recently, the MBTA issued an RFP for a capital budgeting program and requested qualifications for the development of a bridge management system upgrade. This capital budgeting program will not duplicate the work of the bridge management system, but will rather keep a network-level inventory of assets, in order to track condition, maintenance, and help assess repair and replacement needs in order to establish five and twenty-year capital investment plans. The bridge management system upgrades are expected to be implemented in conjunction with a new bridge painting and underwater inspection program and is expected to be compatible with the Massachusetts Highway Department's Pontis system, but no details on the upgrades are available at this time (Prince 1998).

4.3.2.4 Dallas, Texas – Dallas Area Rapid Transit (DART)

DART was chosen for this survey not only for the size of the system, but for the newness of it. It was hoped that their age (2 years) and size (20 miles) would reveal strategies that could directly correlate to those that Tren Urbano could learn from.

DART's maintenance/engineering department is primarily responsible for their maintenance management system. This system maintains an inventory of structures, track, and systems, and keeps inspection records, recommends maintenance options, and provides cost estimation of these options. No network level optimization is performed, and no deterioration modeling is done. This could be due to the age of the system.

The system's strength is its ability to avoid costs by identifying and detecting opportunities for preventive maintenance. DART cites cost avoidance, improvements in safety, and a decrease in service down time as benefits of the system.

Additionally, DART has a Maintenance Document Control System and has been expanded to provide for bridge/tunnel inventory and inspection. These systems are not integrated, and DART believes that integrated systems can be useful provided there is no duplication of effort. DART appears to believe in the importance of infrastructure management, yet does not appear to have made the leap to a fully integrated system which could provide for many more benefits to the entire agency (Warner 1998).

4.3.2.5 Miami, Florida – Metro-Dade Transit Agency (MDTA)

The MDTA has indicated that though they are "not familiar with an infrastructure management system", they believe one would be "probably very useful." Like the MBTA, inspections of structures, track, and systems are done on a regular basis, yet apparently no computerization or automation of this data is performed to monitor conditions or plan appropriate maintenance.

It seems that the MDTA could benefit from an understanding of their infrastructure management process and the potential gains that could be realized by the implementation of an infrastructure management system (Martin 1998).

4.3.2.6 Montreal, Quebec – Société de transport de la communauté urbaine de Montréal (STCUM)

STCUM is a unique transit system that runs on rubber tires and steel wheels. There is no track, and the trains roll on a concrete base. The entire system is 45 miles of concrete tunnel. STCUM indicates that they use an infrastructure management system, but it is neither integrated nor computerized. They maintain an inventory of structures, track, and systems, and perform inspection planning and records archival, but as the system is not computerized, all of the data is presumably kept in paper files.

Each department is responsible for its own organization of information, leading one to believe that there is much duplication of effort wasted in managing their assets.

A preventive maintenance program was begun recently, and the development of an infrastructure management system is mentioned. STCUM recommends the development of such a system with the development of the transit system as the best way to follow the deterioration (Cote 1998).

4.3.2.7 New York, New York – New York City Transit Authority (NYCTA)

The NYCTA indicates that they perform infrastructure management of their system, but they state that there is no comprehensive system. Each department (Track, Structures, and Line Equipment) develops and maintains their own databases for such use.

An inventory of structures and track are kept, and the systems allow for inspection planning, inspection records archival, maintenance recommendations, and cost estimation of these recommendations. Additionally, it is noted that maintenance optimization is performed by each department.

The NYCTA acknowledges one benefit of their management systems being very useful in developing their capital programming budget. The NYCTA also recommends that any system, regardless of age, should implement an infrastructure management program and that inspection, maintenance, and repair records should be kept from the system's start-up (Yanche 1998).

4.3.2.8 San Francisco, California – Bay Area Rapid Transit (BART)

BART indicates that they use an infrastructure management system, but that it is not an integrated system. Rather, each section or division maintains and uses records separately. Inventories are kept of structures, track, and systems elements, and inspection records are archived in these individual systems.

Some modeling of deterioration rates for maintenance planning purposes is done, but this is done on a limited basis. Generally, rail wear and systems deterioration rates are modeled.

The most curious comment on the survey is that earlier attempts at integrating their management systems have failed due to insufficient funding, lack of institutional support, and no integrated approach to the development of such a system. BART is, however, quite aware of the benefits of what an integrated system can do for planning maintenance, storing historical information, and influencing capital budgets. But since they feel that integrating their systems is prohibitively expensive, it is unlikely that any development work will occur in the near future (Leonard 1998).

4.4 Other Systems

Aside from the survey, information on other railway agencies was collected. This data was primarily collected from conversations with professionals working for rail transit agencies, journal publications, and conference proceedings.

As seen from the results of the survey, a market exists for infrastructure management systems, and owners are not quite able to provide themselves with the tools they need to function effectively. Consequently, the private sector has begun to develop this market in order to assist transit agencies wishing to effectively manage their infrastructure assets. This assistance has come primarily in the development of computerized systems designed to perform the day-to-day tasks of maintenance management and infrastructure management, but they may or may not assist in the performance of all relevant infrastructure management tasks.

The New York City Transit Agency has established a state-of-the-art asset management database for use with their 'special infrastructure.' This system, part of a special assessment effort and apparently not a part of their other transit activities, is used to monitor and manage a diverse range of infrastructure assets such as under-river tunnels, viaduct structures, tunnel enclosures, ventilation shafts, pumping stations, special elevated steel structures, and retaining walls. The system is able to store inventory information on this unique network of assets, including defects and condition ratings, recommend necessary short-term and long-term repairs, prioritize work, and develop a capital budgeting plan based on these needs. The result of this assessment program has been a completed inspection and testing effort for a wide variety of infrastructure assets and a completed twenty-year capital program to ensure that the condition of the infrastructure improves (Irshad 1997).

KKO, a private firm, has developed an integrated infrastructure management system for all assets (structures, rolling stock, communications and signals, track, and power) for AMTRAK, and a similar system for the San Diego Trolley. KKO has also been contracted to develop a management information system for Tren Urbano, although the requirements of this system are not distinctly known at this point (Beneda 1998).

Goodkind & O'Dea implemented a bridge management system for use by New Jersey Transit/Metro North. This system, called BRIMMS (Bridge Rehabilitation Inventory and Maintenance Management System), is a computerized management system that maintains an inventory of bridges, culverts, tunnels, their condition and performance ratings, and maintenance plans. Based on this information, deterioration models are developed to analyze potential future needs. It then can prioritize bridge rehabilitation and maintenance work based on the ratings, urgency, or network importance and can establish lifecycle strategies for the entire bridge network (Blatz 1996).

Zeta-Tech has developed a system of structural, track, and systems management for Conrail/CSX (Beneda 1998).

Environdyne Engineers have developed a structural, track, and systems management system for the Chicago Transit Authority's (CTA) aging infrastructure. This data management system gives the CTA the ability to analyze and present data that allows the CTA to make capital budgeting decisions. By using a relational database, data from various subsystems, numbered with different systems, can be graphically related in a very easy manner (Huguet 1997). The final system implemented for the CTA records a complete inventory of the infrastructure elements, condition ratings, defects, and preventive maintenance plans. It then produces reports that list defects, repair orders, and maintenance needs for each element, but performs no modeling of deterioration. This information is the utilized by the capital budgeting module to select projects for capital funds, set priorities of work, track cost versus budget and facilitate coordination with maintenance concerns (Environdyne Engineers 1997). This type of system was developed because of the need to capture all inventory and condition data to recommend repairs, and because of federal pressure to use modern methods to manage funds. This product is not mass-marketed, as it needs a great level of customization to install and use (Griffis 1998).

WMATA has indicated that although they do not have any type of infrastructure management system, they are very interested in implementing a system similar to the system in Baltimore. LACMTA has indicated that they have no computerized database of infrastructure assets, but that each division does maintain an inventory of assets in spreadsheet form and this was developed in-house (Beneda 1998).

Considering all of the duplication of effort involved in these systems, which are presumably attempting to solve all of the same problems, the efforts of the American Railway Engineering Association (AREA) Committee 32 – Engineering Management Systems to standardize these systems becomes quite relevant. The assumption of this committee's work is that these systems have been shown to be beneficial to a railway, but through standardization, a railway can achieve greater capability, more compatibility, and easier maintenance of the management systems themselves. The committee asserts that each railroad must perform very similar functions, but the duplication of effort between railroads, between departments within railroads, and even between sections of the same department, has created many problems when trying to integrate their knowledge outside of their organizational boundaries. The committee presents quite a detailed view of what a standardized system could look like, but has yet to make the leap to developing any software systems due to the disinterest of the industry, which is either content with their own development efforts or unable to fund a new development effort. This is an unfortunate, but realistic view of the ability to standardize the management systems of railroads and rail transit providers (Bartholomew 1997).

4.5 Summary

The systems that were presented in this chapter are common in the sense that all are essentially database-based programs used to track maintenance and inspection data over a network of assets. Some perform optimization; some do not. Some are network level decision tools and some are not. Some utilize modeling to determine future needs and others do not. What this means is there are a lot of options available to a newly built transit system. It is important for a transit agency looking to develop a system like these to establish their goals and needs early in the development, and to systematically approach the process to ensure that all needs are identified and all tasks are performed.

This chapter also showed the various types of approaches that owners have taken in the development of their various infrastructure management systems. Some definitely appear to understand the importance that such systems can carry in their organizations. The most important point to take away from this chapter is that these systems, if implemented and utilized to meet an agency's needs, give agencies the ability to monitor actual costs of service provision in a way that is useful for future planning purposes.

5 Proposed Framework of Infrastructure Management

5.1 General Review

Chapters 1, 2, 3, and 4 were very much concerned with establishing the background and presenting the data gathered for this thesis. It is at this point in the thesis that all of this background, data, and related analyses will be used to build an integrated framework of infrastructure management. Chapter 2 presented many theories and ideas about infrastructure management. Five primary solution types were identified to improve the state of our infrastructure: more money, innovative technologies, increased efficiencies, changes in government involvement, and increased use of automation and management systems. The specific nature of the factors that relate to the first three make analysis difficult here. But the last two provide ample opportunity for a generalized approach. Chapters 3 and 4 both outlined the current use of alternative delivery methods and management systems. Both strategies are individually useful, but together they form an entirely new model of infrastructure management. But it becomes clear that only when a government is able to clearly identify its costs of infrastructure provision is it able to attract private sector partners. Infrastructure management systems help to identify these costs.

An integrated infrastructure management process must identify the costs and benefits of infrastructure service provision in order to evaluate opportunities for changes in that service provision. Conversely, integrated delivery methods can provide the incentive to consider lifecycle costs, and thus necessitate the use of an infrastructure management system. This relationship, described in chapter 2 and shown in *Figure 2-3*, will be utilized in this chapter to introduce a framework for infrastructure management.

5.2 Integrated Framework of Infrastructure Management

This framework is based upon several key concepts:

1. The operational tasks concerning data management, needs analysis, alternative maintenance options, and work programming are fundamental to infrastructure management and must be coordinated with all infrastructure assets.

2. The institutional issues of feedback and influence are fundamental to organizational control and flexibility in the operational tasks.

3. Each phase of the lifecycle must be considered when making decisions in order to have an ability to minimize lifecycle costs.

4. Computerized management systems help to identify service provision costs when implemented in an effective way.

5. Integration of lifecycle phases can lead to lower lifecycle costs, longer service lives, and increased infrastructure service quality.

As defined in chapter 2, infrastructure management is the sum of the decisions, policies, and practices that are adopted with respect to the delivery of or the maintenance applied to any infrastructure asset or network of assets. The goal of effective infrastructure management is to minimize lifecycle costs of infrastructure service provision. Effective infrastructure management insinuates that owner actions are based on an understanding of the infrastructure's functional importance. These actions should be more proactive or preventive in nature, and less reactive. Effective infrastructure management does not get caught up with the individual condition ratings or performance standards of assets, except as they relate to service provision over the entire network of assets.

These owner actions are stratified here to illustrate the three levels at which an owner must concentrate its efforts. Level 1 is defined as the specific tasks that must be performed at the operational level of the infrastructure management process, and includes all data collection, modeling, and alternatives analysis. Level 2 is defined as the input/output and feedback phases of information flow in the infrastructure lifecycle phases, and the interrelationships and responsibilities that each party must be aware of to enable the level 1 tasks. Level 3 is defined as the institutional issues that affect the management of the level 2 tasks, and provide the foundation for performing the level 1 tasks. Each level has its own issues that must be resolved and its own agenda that must be satisfied. *Figure 5-1* shows these levels, which will be explained fully below.

5.2.1 Level 1. Infrastructure Management Tasks

An effective infrastructure management process must follow a systematic process of operation and evaluation. A typical framework for efficient infrastructure management in level 1 will include tasks under the following four headings: Data, Needs, Alternatives, and Programming.

Level 1 tasks proceed in linear fashion, as each completed task enables the next task to be performed. Establishing the inventory of network data and industry data in a usable format is the first task that must be completed, and this is preferably done during the design and construction phase. It is much more difficult to collect network-specific data once operations begin, due to the excess costs and effort required. The duplication of effort required to re-establish the inventory during operations would be wasteful. *Figure 5-1* shows the relationship between each level 1 task and the level 2 lifecycle phases.

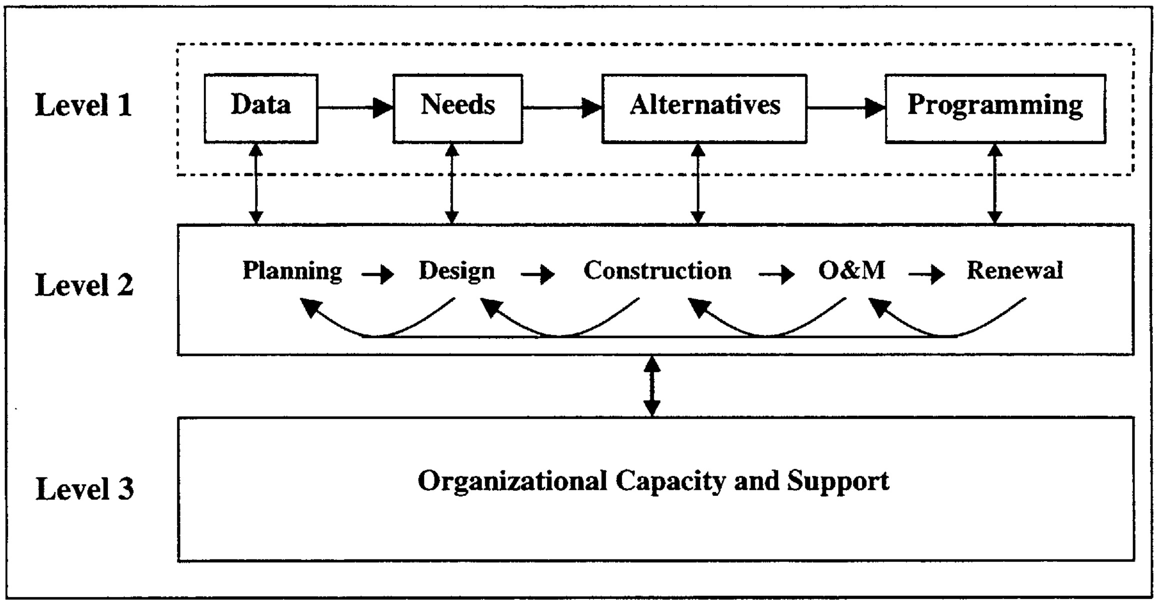

Figure 5-1 Graphic Representation of Infrastructure Management Levels

Without an inventory, it is impossible to implement useful inspection or testing programs from which to determine the current needs, which are based on the current condition and performance ratings. Knowing the current needs, and having a systematic method of reporting them, allows for modeling to determine potential future needs. These future needs are based on deterioration and maintenance policy assumptions. Changing these policy assumptions in the modeling can indicate the sensitivity of the infrastructure network to these policies.

By understanding the costs and benefits of alternative maintenance options and their effect on deterioration rates, service lives, and lifecycle costs, optimization can be done to minimize the costs of maintaining an acceptable level of service over the network of infrastructure assets. This systematic optimization is necessary to recommend a work programming effort.

This really is a fundamental change in the way these tasks have been performed. Most owners plan maintenance and improvement projects on a case-by-case method, based only on current conditions. This network level approach forces owners to understand the costs and benefits of each available alternative over the entire network before committing to a plan of action, thereby giving them the confidence that their actions are fundamentally sound and beneficial to the entire network of infrastructure assets. It is this confidence that allows owners to understand their business processes and make necessary adjustments.

By performing these level 1 tasks correctly, it allows the level 2 and level 3 tasks to be taken more seriously. When the level 1 tasks are based on good data and processes, the feedback becomes much more important and reasonable, while the trust in the output becomes more believable and useful for influencing capital programming and on-going infrastructure planning.

Data includes the collection of both network-specific information and industry-known information. Network-specific data includes an inventory of all infrastructure assets, such as asset type, location, quantities, and construction material. These can typically be gathered through both visual inspections and historical records. This 'base-plate' data is the most important step in the process, simply because the inventory provides the foundation for the entire process. Industry-known data includes information on all available maintenance processes and capabilities, for all assets. This includes typical maintenance, repair, and rehabilitation (MR&R) actions and their associated lifecycle costs, and the action effectiveness of each MR&R option. Determining associated costs and action effectiveness is quite difficult, however, and requires historical records, industry research, and expertise in maintenance engineering.

Needs encompasses both present needs and predicted future needs based on current condition or performance ratings and historical records. The ratings are obtained through field inspections, testing procedures, and system modeling. These current needs are then used to predict future needs with the help of deterioration models. Previously, condition assessments were the only basis for programming decisions. Recently, however, infrastructure managers have begun stressing the importance of performance assessments, either in tandem with condition assessments, or as stand-alone ratings. Both are important, and reasonable weighting should be given to both assessments to obtain a valid picture of the importance of the asset.

An important discussion at this point should point out the difference between visual inspection data and testing data, both of which can provide an understanding of condition states of an asset. But these two methods are very difficult to coordinate or translate between. Typically, testing results are used to enhance visual data on a specific basis. This means that visual inspections generally will control the decision to repair an asset or not, but specific testing data can help to reveal optimum strategies to fix specific problems. However, current management systems cannot effectively utilize both visual data and testing data for two reasons. First, the sheer volume of data typically gathered from testing procedures is not easily digested by management personnel. Second, no clear correlation can be identified between visual condition states and testing results due to the extensive and specific nature of the tests. It is for these reasons that many agencies rely on visual inspection data for their inspection needs. Visual inspections, though far from complete (only what can be seen can be analyzed), can be easily compared.

Alternatives studies all of the possible actions to perform on a given infrastructure asset, based on its individual condition or performance rating. These alternatives are influenced by policy and current capabilities. Each asset type in each condition state or performance state might have a variety of potential MR&R actions to address its deficiencies. It is important to identify all of these actions, understanding that each has a different effect on the condition and performance of the asset. Also, each alternative action has different costs and benefits that must be identified. This task must be structured to enable both innovations in methods and materials.

Programming is the step when the needs and alternatives are combined with known funding constraints and policy choices. Prioritization of potential actions based upon some predetermined methodology must be done in order to enable efficient network-level decision-making. It is important to note the distinction that a network-level view provides here. Rather than looking at the necessary actions to bring each asset to some predetermined engineering standard, it is imperative that actions are programmed which allow the full network of assets to function as needed.

Here the difference between the funding of capital improvements and maintenance options can become a hassle. The best action could be a repair, but funding might only exist for replacements. This acts as a deterrent to choose an action that minimizes lifecycle costs of providing infrastructure services, since funding from another source does not affect an agency's bottom line. Other people's money is much easier to waste. This approach can encourage overbuilding and the neglect of routine maintenance.

5.2.2 Level 2. Infrastructure Management Lifecycle Phases

The tasks mentioned in level 1 are crucial to the effort of effective infrastructure management. However, they neglect to address the human nature of the owner agency, which can typically get caught up in performing individual tasks while neglecting the ultimate goals. Additionally, infrastructure management can not be thought of as simply the responsibility of one individual or department, but rather, must be viewed as each participant's responsibility over the entire lifecycle.

Only when all participants consistently engage the process of infrastructure management and fulfill their own obligations to the upkeep and reliability of the process will it be effective. This could involve a culture change within an organization trying to implement efficient infrastructure management or, if an agency is new, then the culture could be built into the organization from the start. *Figure 5-1* shows the relationships between each lifecycle phase. In level 2, the right-facing arrows indicate the flow of time, while the left-facing arrows indicate the flow of feedback through the process.

To see the interdependence that each lifecycle phase has on the entire lifecycle, an understanding of all phases is crucial. The first phase is defined as Planning, which includes all conceptual design and feasibility studies performed by the owner once a need has been identified. The second phase is Design, which includes both preliminary and final design. The third phase is Construction, which includes all activities up until the start of service of the asset. The fourth phase is Operations & Maintenance, which includes all tasks related to the operation of the asset, including routine and preventive maintenance, inspection, management, repair, monitoring and evaluation throughout the remaining life of the asset. Finally, the fifth phase is Renewal, in which the asset is renovated, demolished, replaced, or otherwise taken out of useful service. This fifth phase also helps to identify new needs, cycling back to the Planning phase.

These relationships are shown in two flow diagrams. *Figure 5-2* illustrates the typical ineffective model of infrastructure management used by many owners. *Figure 5-3* illustrates an effective model of infrastructure management.

Figure 5-2 shows the planning, design, and construction of an infrastructure asset as distinct items. These three steps establish the inventory of the system, which is then put into service. Typical operations, inspections, and maintenance are performed, based on budgets and policies handed down from other sources. Generally, funding constraints will limit the maintenance actions performed on the entire network. This leads to more costly repairs, rehabilitations, and replacements during the asset's lifecycle. No real feedback or influence over the capital or maintenance budgeting process is seen by the network operators or engineers.

Figure 5-3, on the other hand, attempts to diagram a more effective infrastructure management process for use by these same agencies. Again, planning, design, and construction establish the initial inventory, while operations, inspections, and routine preventive maintenance are performed. In this scheme, however, the budget and policy for maintenance actions is influenced by the perceived needs of the system operators, based on clearly identified condition and performance standards. The use of an infrastructure management system supports this process by identifying maintenance actions that minimize the lifecycle costs of providing the infrastructure services. Additionally, the accumulated cost and effectiveness data in the infrastructure management system can be used to support the capital budgeting and planning process. This assists an agency that is looking to deliver projects using alternative delivery methods by identifying lifecycle cash flow projections for future projects, based on data from previous projects.

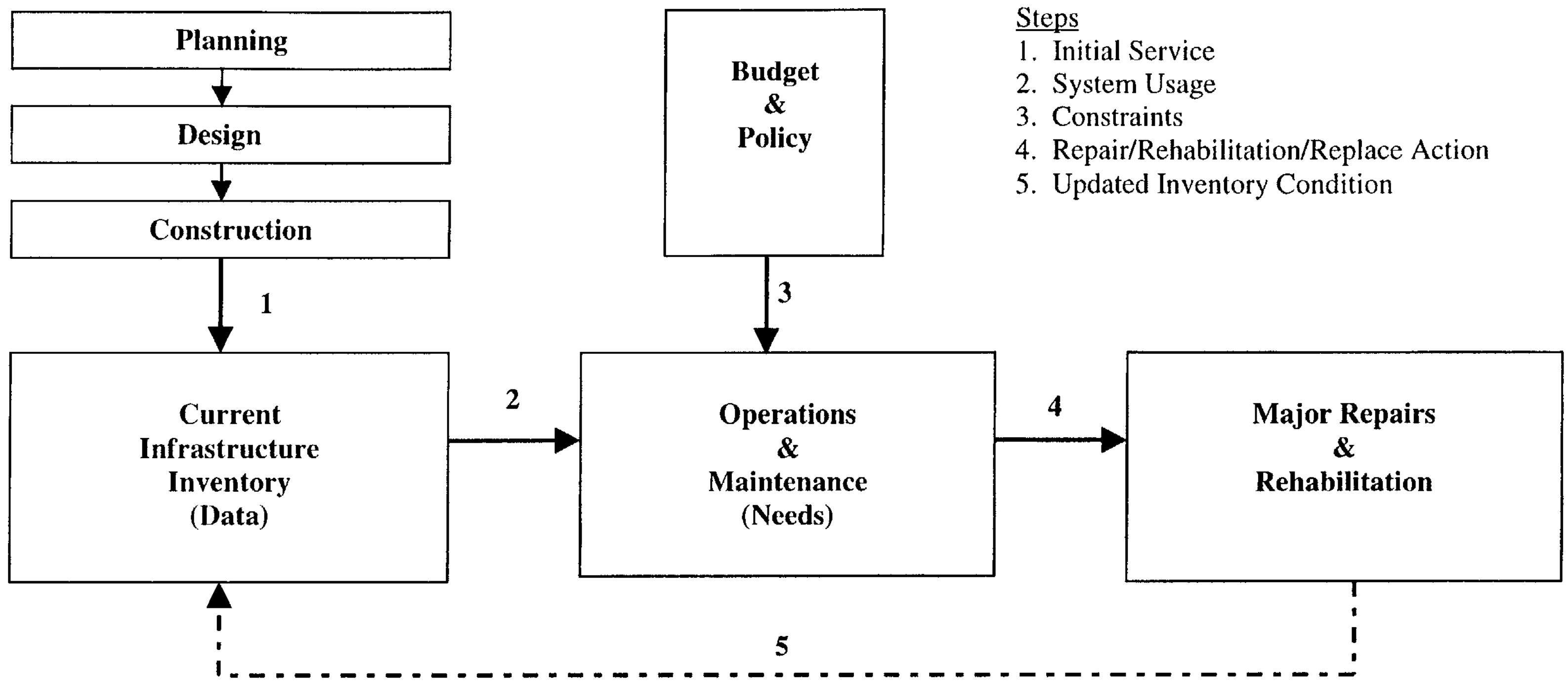

Figure 5-2 Ineffective Infrastructure Management

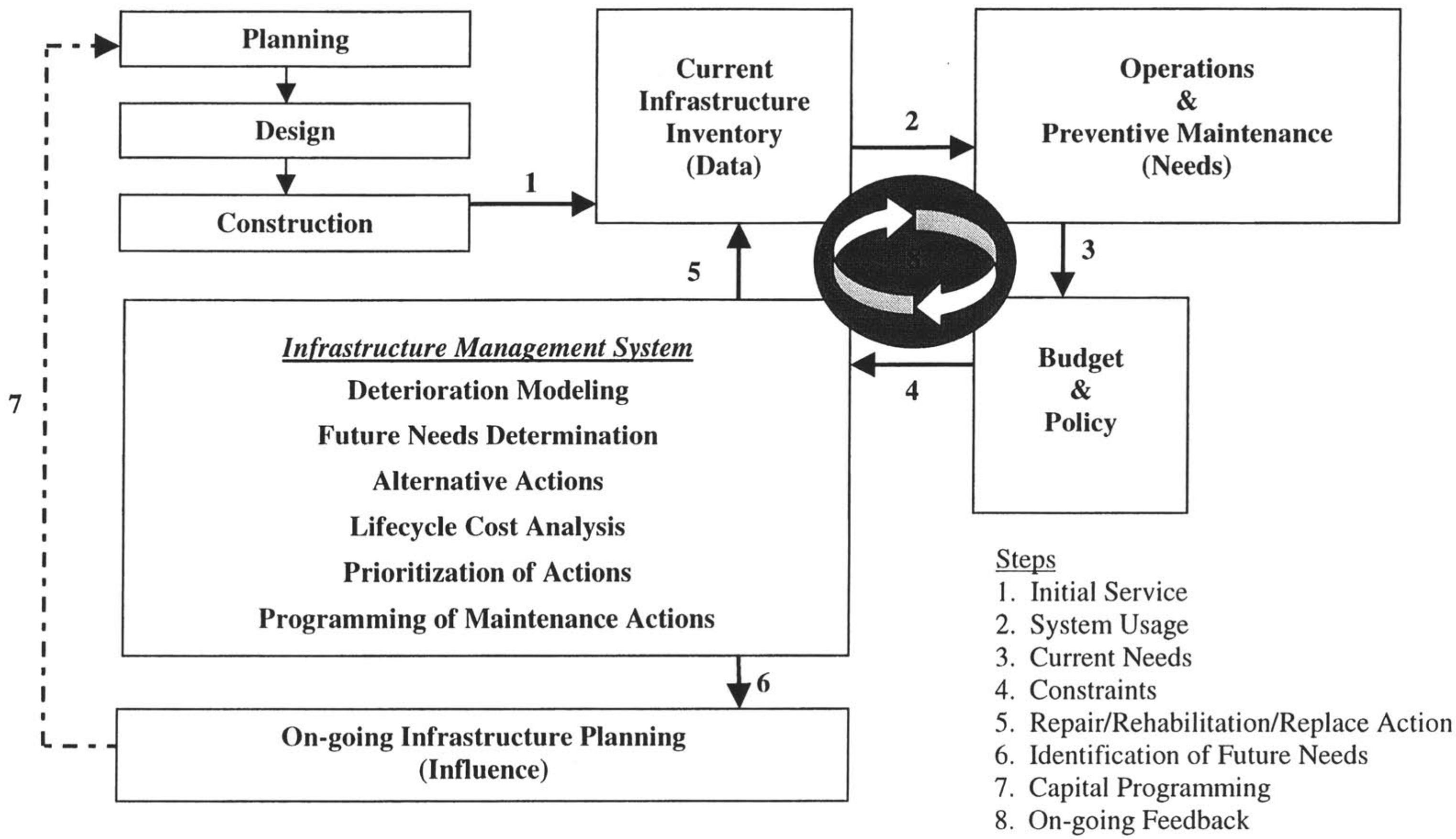

Figure 5-3 Effective Infrastructure Management Process

5.2.2.1 Level 2 Coordination

Planners, designers and constructors, or those overseeing planning, design, and construction are instrumental to building the initial inventory, and building this inventory during the design and construction phases will eliminate any duplication of effort during the operations & maintenance phase. Inspection and maintenance performed during operations must be recorded and evaluated in order to update the inventory periodically. Maintenance engineers must lend their expertise on repair options and associated costs, and managers must lend their organizational support to the process. In short, the entire agency must be willing to engage the process of efficient infrastructure management.

One distinct problem in this scheme is a lack of incentives for certain personnel to perform effectively. System operators, maintenance planners, and administrators have the most need for reliable outputs from the process, while inspectors, maintenance personnel, and engineers have the vital information to be entered into the process. The former must be assured that the latter are diligently following the process, while the latter must be assured that their efforts are not being wasted. This could be a dilemma in agencies with morale trouble or a lack of consistent leadership. Integrating the various lifecycle phases, through the use of integrated delivery methods, can help to avoid these issues, since each participant has a stake in the performance of other tasks by other participants.

It is equally important that level 2 promotes feedback within the relationships between each participant in the lifecycle and within the process itself. **Feedback** is the step where lessons that have been learned in the previous level 1 tasks are passed back into the process so that changes can be made to take advantage of the new experience and knowledge.

5.2.3 Level 3. Infrastructure Management Organization

Effective infrastructure management must be an integral part of an owner's mission or strategy, and this message must be clear to all personnel. It is assumed here that a well-maintained inventory of infrastructure assets is generally in the best interest of an owner, and should therefore be given high priority in any organization. Quality of service generally depends heavily upon the quality of infrastructure assets. Effective infrastructure management is crucial to the organization, and a systematic infrastructure management process will enable effective decisions to be made. However, this will happen only if all participants are well informed as to the nature of the problems facing the agency, and are convinced that the methods being utilized to solve the problems are valid. This takes leadership. *Figure 5-1* indicates the relationship of level 3 to levels 1 and 2 as that of a foundation supporting the operational and institutional tasks of infrastructure management.

It is crucial to solve these institutional issues as early as possible in order to allow an organization to function as intended. These non-technical issues can affect the success or failure of an agency's attempts to institute changes in their infrastructure management policies. Common issues that have been identified are: resistance to change, turf battles, job security fears, lack of communication, and misunderstanding of responsibilities. Efforts should be taken to identify and address these issues as soon as possible when implementing any sort of process or business change, and this applies equally to any changes in infrastructure management policies and processes (Zimmerman 1993).

One consequence of these institutional issues is the level of trust that is placed upon the process of infrastructure management and consequently, the results of the level 1 tasks. Any feedback or recommendations that come out of the infrastructure management tasks must be trusted. **Influence** is the last goal in the infrastructure management process that must be met. This institutional trust influences decision makers in the choice of using or not using the results of the process to help make decisions on capital budgeting or delivery methods for future projects.

5.3 Infrastructure Management QuickTest

In order to determine if an owner is effectively managing a diverse set of infrastructure assets, several key questions must be asked. These questions, in the form of an Infrastructure Management QuickTest, will enable an owner to understand the status of their infrastructure management process and where the information flow is being stopped and interrupting effective service provision. The following sections introduce the questions of the QuickTest. If all of the questions can be easily and accurately answered, then this is an indication that an owner can make well-informed decisions to effectively manage the infrastructure asset network. (See Appendix C for the actual QuickTest document.)

5.3.1 QuickTest - Level 1

5.3.1.1 Data – Network Specific

What infrastructure assets do we own?
What is the geographic location of these assets?

These are the most basic of the questions. An up-to-date, factually correct inventory of all infrastructure assets is fundamental to effective infrastructure management. Inventory data should be continuously subject to Quality Assurance and Quality Control procedures because of its importance to the rest of the process. Bad data, or inconsistent data, could be the downfall of even the best infrastructure management process.

5.3.1.2 Data – Industry Known

What MR&R options are available to our network of assets?
What costs and benefits are associated with these options?
What action effectiveness is gained from these options?

It is equally fundamental to understand the MR&R actions that are available to perform on the identified infrastructure assets, with their associated lifecycle unit costs and benefits. This allows for standardized comparison of options later in the process.

5.3.1.3 Needs – Current

What is the current condition of each infrastructure asset?
At what performance level is each infrastructure asset?

Identifying the current needs in terms of both condition and performance allows for the understanding of all potential risk factors affecting the infrastructure asset network (Das 1996). Considering the condition of an asset takes into account the deterioration of the asset, and considering the performance of an asset takes into account other risk factors, including over-use, under-design, or changing technologies. Historically, condition was the primary method for rating infrastructure. But in recent years, the shift to considering the performance of an infrastructure asset has allowed more rational maintenance decisions because a focus on performance leads to improved network efficiency (CBO 1986).

5.3.1.4 Needs – Future

What is the remaining design service life of each asset?
At what rate is each infrastructure asset deteriorating?

Identifying future needs takes a little more effort. Condition and performance can be modeled based on historical records and current assumptions in order to provide a 'guesstimate' of what future conditions or performance may be. The future needs can be used to weigh options based on lifecycle planning considerations when considering alternatives.

5.3.1.5 Alternatives

What effect will various MR&R actions have on:

a. Deterioration rates?
b. Service lives?
c. Lifecycle costs?
d. Budget constraints?
e. All of the above, considering the entire network of assets?

In this phase of the infrastructure management process, an owner can understand all available options based on systematic reasoning. These alternatives must be based on two key principles. First, the lifecycle cost of each alternative must be known. Second, evaluation of benefits and costs must be made consistent for different types of infrastructure assets in order to make useful comparisons. If an owner can understand these effects, then the way is paved for intelligent programming choices.

5.3.1.6 Programming

Which combination of projects will minimize the lifecycle costs of service provision?

This is the crux of effective infrastructure management. An owner that is able to apply systematic reasoning to the allocation of limited funds over the infrastructure asset network is an effective infrastructure manager. When budget and policy constraints are being addressed responsibly and priorities have been established, the implementation of optimal MR&R programs is inevitable.

5.3.2 QuickTest - Level 2

5.3.2.1 Feedback (Integration)

What have we learned from this process?
What data reporting mechanisms are needed to ensure an efficient flow of information?
Where could lifecycle phase integration bring about service improvements?

Effective infrastructure management allows for lessons to be learned from the entire infrastructure management process over the entire lifecycle. For example, operators could recommend design changes to improve service quality, or historical records could provide insight into potential maintenance improvements. Creating a systematic method for enabling and controlling this institutional memory is an important, albeit difficult, aspect of effective infrastructure management. It is through this systematic approach to feedback that policy, practices, and decisions can be adapted to suit the long-term needs of the owner.

Additionally, it is important to record and analyze the cost and benefit data from previous maintenance actions in order to assess the usefulness of those actions and strategies. This also allows the assumptions of cost or effectiveness to be tested or quantified further.

5.3.3 QuickTest - Level 3

5.3.3.1 Influence (Capital Budgeting)

How can capital budgets be improved from this process?
What changes in project delivery would provide enhanced network performance?

An infrastructure management process must have influence within the organization's decision-making authorities in order to be effective. The trust that each participant has in the output from the process affects the decisions that are made with the output.

5.3.4 Framework Review

This is an attempt to present a framework for understanding where an owner is in the process of implementing effective infrastructure management and why they are at that level. Inability to easily answer any question should be traced to its source and dealt with there. While this may seem oversimplified, the idea is to attack this from a global perspective of how an agency manages its infrastructure. The steps an agency must perform to begin this process, as well as the information that needs to be known about how an agency operates (i.e. cost data, work processes, etc.) all need to be determined in this framework.

So within this framework, eight different steps have been identified to measure an agency's infrastructure management process: Data – Network, Data – Industry, Needs – Current, Needs – Future, Alternatives, Programming, Feedback, and Influence. For simplicity, one point will be awarded within this framework for each step that an agency or system performs or fulfills in the process. A half point will be awarded for each step that is partially fulfilled, although this only applies in very limited instances. So a perfect score indicating that an owner has a fully functioning effective infrastructure management process would be eight.

In the last chapter, several in-place infrastructure management processes were described. This framework will be applied to those same agencies to compare criteria and development attributes

5.4 Survey Results – Framework

A framework for analyzing where an owner stands in the development of an infrastructure management process was just presented in the form of a quick test to be taken by an infrastructure owner or manager. This framework was applied to the urban rail transit agencies that responded to the survey and is based upon both information provided in the survey and information found from other sources about the agency. As described above, a perfect score is 8. An agency utilizing the capabilities of the Pontis bridge management system, for example, would likely score an eight based upon the process it enables. The following section presents the results of applying the framework to the seven systems used in the survey and the rationale behind the scoring.

As a reminder, one point can be awarded for each of the eight tasks, including Data – Network, Data – Industry, Needs – Current, Needs – Future, Alternatives, Programming, Feedback, and Influence. Points are given in parentheses after the rationale. 1 indicates that the task is performed. ½ indicates that it is partially performed. 0 indicates that it is not performed, and X indicates that not enough information could be found to determine whether the task was being performed.

5.4.1 Points Rationale

The basis for giving points in each category is provided here. For Data – Network, an indication of an integrated inventory of structures, track, and systems, as well as inspection/testing records and reports archival will score a 1. Any mention of separately maintained inventories between departments will score a ½. For Data – Industry, an indication that maintenance and repair possibilities, and their associated costs, are known will score a 1. For Needs – Current, an indication that inspections are performed and records are kept will score a 1. For Needs – Future, some sort of modeling or predictive deterioration will score a 1. Minimal or limited modeling will score a ½. For Alternatives, a network-level analysis of lifecycle cost alternatives for maintenance and repair will score a 1. For Programming, some indication that the work programmed is based on the identified alternatives being optimized considering budget and policy constraints will score a 1. For Feedback, any mention of lessons learned or institutional memory will score a 1. And for Influence, the determination of network-level needs must have some influence on capital programming to score a 1, while a score of ½ will be given to agencies recognizing the importance of such a process. *Figure 5-4* summarizes these results.

5.4.2 Agency Analysis

MARTA received a total score of 4½. Based on survey results and conversations with personnel at MARTA, it was determined that a complete inventory of network assets was kept (1), and comparison of maintenance practices was made with industry standards (1). Inspections are regularly performed and preventive maintenance is typical (1). Modeling of deterioration to determine future needs is minimal, however (½), no specific mention is made of analyzing alternatives in maintenance planning (X), and programming is still done at a department level (0). Their system does evaluate processes for improvement and cost reduction (1), but no mention is made of the influence of this system on the capital budgeting process (0).

Baltimore-MTA received a total score of 4. Based on the survey results and other sources, it was determined that a complete inventory of all infrastructure assets was not centrally maintained (½), but knowledge of current industry maintenance practices and costs was known (1). Their inspection schedule indicates that they collect and know their current needs (1), although no modeling of deterioration to determine future needs is performed (0). Since integrated network data is not kept, comparing alternatives is not possible (0), and neither is programming based on network-level needs (0). Feedback through their process is indicated however (0), and some influence on their capital budgeting is obtained (½).

MBTA received a total score of 1½. Based on survey results, it was determined that complete inventory could not be given due to the separate collection of network data (½), and no mention was made of useful collection of industry data (X). Their inspection schedule indicates that they collect and know their current needs (1), although no mention is made of modeling deterioration to determine future needs (X). Since integrated network data is not kept, comparing alternatives is not possible (0), and neither is programming based on network-level needs (0). No mention is made of a feedback process (X), and no influence on capital budgeting is possible without integrated network data (0).

DART received a total score of 2½. Based on survey results, it was determined that separate inventories are maintained by each department (½), industry data is kept (1), and current needs are known (1). The survey also indicates that no modeling is done to determine future needs (0). Since integrated network data is not kept, comparing alternatives is not possible (0), and neither is programming based on network-level needs (0). No mention is made of a feedback process (X), and no influence on capital budgeting is possible without integrated network data (0).

MDTA received a total score of 1½. Based on survey results, it was determined that separate inventories are maintained by each department (½), no mention is made of network data (X), but inspections lead to known current needs (1). No mention is made of modeling to determine future needs (0). Since integrated network data is not kept, comparing alternatives is not possible (0), and neither is programming based on network-level needs (0), and the survey corroborates both assumptions. No mention is made of a feedback process (X), and no influence on capital budgeting is possible without integrated network data (0).

STCUM received a total score of 3. Based on survey results, their inventory is neither computerized nor integrated (½), and no mention is made of industry data (X). A recently instituted inspection program has yielded current needs (1), and these needs were used to model future needs (1). Since integrated network data is not kept, comparing alternatives is not possible (0), and neither is programming based on network-level needs (0). No mention is made of a feedback process (X), and no influence on capital budgeting is possible without integrated network data, although their modeling efforts have yielded a twenty-year capital plan (½).

NYCTA received a total score of 3. Based on survey results, their inventory is kept separately by each department (½), they collect industry data (1), and their inspection program has led to current needs (1). No modeling is done to predict future needs (0). Since integrated network data is not kept, comparing alternatives is not possible (0), and neither is programming based on network-level needs (0). No mention is made of a feedback process (X), and though no influence on capital budgeting is possible without integrated network data, they have knowledge of the importance of such programming and feedback on capital planning (½).

BART received a total score of 4½. Based on survey results, they maintain separate inventories of assets in each department (½), collect industry-wide data (1), and inspect their assets to determine their current needs (1), but modeling is done on only a limited basis to determine future needs (½). Since integrated network data is not kept, comparing alternatives is not possible (0), and neither is programming based on network-level needs (0). Feedback is gained by giving participants immediate access to information (1), and though no influence on capital budgeting is possible with integrated network data, they understand that such records are essential to long-term planning (½).

	MARTA	BaltMTA	MBTA	DART	MDTA	STCUM	NYCTA	BART
Data – Network	1	½	½	½	½	½	½	½
Data – Industry	1	1	X	1	X	X	1	1
Needs – Current	1	1	1	1	1	1	1	1
Needs – Future	½	0	X	0	X	1	0	½
Alternatives	X	0	0	0	0	0	0	0
Programming	0	0	0	0	0	0	0	0
Feedback	1	1	X	X	X	X	X	1
Influence	X	½	0	0	0	½	½	½
Score:	4½	4	1½	2½	1½	3	3	4½

Codes: 1 = Yes; 0 = No; ½= Partial; X = Unable to Determine

Figure 5-4 Results of Framework Analysis

5.4.3 Review

As shown in this analysis, BART and MARTA have the best scores. But none of the transit agencies are performing up to or close to the level of effective infrastructure management (Score of 8). The primary fault that keeps most agencies from scoring higher is the lack of an integrated inventory from which to make network-level programming decisions. Due to the generally sequential nature of this framework (i.e. Each task performed is preceded by performed tasks), a score of more than three indicates that some action beyond keeping records is being performed and owners are aware of the benefits of infrastructure management. In fact, most of these agencies did indicate knowledge of the benefits. A score of three or less, on the other hand, indicates that these records are not being used for any type of modeling or decision-making capabilities. These results stress the importance of maintaining a complete inventory of assets, rather than keeping records in different departments, which tends to duplicate efforts and make information retrieval difficult. Some of these scores would be distinctly higher if the tasks were performed at the network level, since it is the assumption of this research that integrated data is essential to infrastructure management.

5.5 Academic Strategies vs. Practical Applications

This framework highlights one issue in particular in the quest to determine applicable strategies for urban rail transit agencies. A gap exists between the academic models that have been proposed and the actual policies and practices of the industry, and no solutions have been useful in converging upon an acceptable practice. This gap is not easy to explain. The industry officials consulted in this research are not dumb. They have an acute awareness of the problems they are facing, and are trying to address them using the best technology and management skills available to them. But the following problems contribute to this gap:

- **Budget Constraints.**
  Limited funding has caused many agencies to defer maintenance that is not absolutely crucial to providing transit services. Additionally, earmarked budgets tend to favor initial construction over maintenance actions.

- **Cost Prohibitive Solutions.**
  Many solutions that could work have too high a price tag. This apparently includes some infrastructure management systems, and many new materials and methods.

- **Separate Budgets for Separate Inventories.**
  Optimized solutions are only possible over a local, not global, domain of assets. Perhaps the rail infrastructure has plenty of funding while the structural infrastructure is lacking the necessary investment.

- **Communication Failures.**
  A lack of communication between the different participants at all levels can cause good ideas and new techniques to be ignored and can promote obsolete solutions.

- **Political Factors.**
  It's the sad truth that short-term solutions are valued more than long-term solutions to public officials who are trying to get re-elected.

- **Lack of Cost Data.**
  It is impossible to identify cost-effective solutions if the detailed costs of providing services cannot be determined.

There is no quick fix to any of these issues. However, a new attitude towards and framework of infrastructure management, as presented in this chapter, could have the effect of bringing together all of the participants in the infrastructure lifecycle to identify and mitigate these and other risks facing the provision of infrastructure services. Also, this framework recommends methods that can help to overcome these specific issues facing transit agencies nationwide.

5.6 Summary

This chapter presented a framework of infrastructure management that can guide an owner when developing an infrastructure management process. This framework is based on the concept that infrastructure management systems can assist in the maintenance programming decisions of a transit agency, while also providing detailed cost data that supports future planning. Integrating these systems with the planning process can lead to better decisions, including the use of alternative delivery methods, based on lifecycle cash flows. This chapter also developed the concept of the Infrastructure Management QuickTest that can help to determine an owner's ability to effectively manage their assets.

The application of the framework, and the subsequent analysis, gave an interesting insight into transit agencies and their attitudes towards infrastructure management. Most understood the potential benefits of implementing an infrastructure management process, but none could truly quantify these benefits. Their actions then led to a gap between the recommendations provided by the academic literature and their own practical experience. In order for effective infrastructure management to occur, this gap must be bridged. This could occur either with better, more relevant research, or through improved use of modern strategies by transit agencies.

6 Tren Urbano

6.1 General Review

6.1.1 Overview and History

Puerto Rico, a commonwealth of the United States, is a Caribbean island located to the east of the Dominican Republic. This island, with a population of over 3.7 million, has an area of approximately 3,245.6 square miles, giving Puerto Rico a population density of 1,140 people per square mile (USDOT 1995). The capital of Puerto Rico is San Juan, which is on the eastern portion of the north coast of the island.

The San Juan Metropolitan Area (SJMA) consists of twelve different communities. These are Bayamón, Canóvanas, Carolina, Cataño, Dorado, Guaynabo, Loíza, Río Grande, San Juan, Toa Alta, and Trujillo Alto. The SJMA, naturally bounded in all directions, is approximately 400 square miles in area, with a population density of 3,230 people per square mile, making it one of the fifteen most densely populated areas in the United States. In the densest portions of San Juan, densities approach 20,000 people per square mile (BAA 1993).

Along with population densities, car ownership is especially high in Puerto Rico. There are 146 vehicles per mile of paved road, which is the highest in the world, and in the SJMA, there are 4,286 cars per square mile. Only 23% of the major streets have four or more lanes. In 1990, almost 50 percent of the directional lanes were congested during rush hours, and congestion costs in lost gasoline are $100 million each year (TUO 1994).

6.1.2 Transportation Studies of the SJMA

The economic growth of the region since World War II has put an incredible strain on the entire transportation infrastructure, and the growth in population has not seen an associated growth in infrastructure investment to serve the SJMA. These trends have been recognized for some time in San Juan, and several major transportation studies have been performed to identify a strategy to cope with and direct the growth in the region.

In 1967, Wilbur Smith & Associates looked at the 1985 projected population, car ownership, and land-use alternatives and recommended the development of a two-line transit system. This 27-mile system would also be complimented by an extensive bus and público system.

In 1979, CTA/Alan M. Vorhees attempted to identify the locally preferred option for the SJMA to address their transportation concerns. The options considered were a rapid rail transit system under various alignment alternatives, light rail or express bus technology, or low-capital traffic engineering and regulatory alternatives. The final recommendation found that the population and urban structure of the SJMA make a rapid rail transit system the most obvious choice, with no viable alternatives to this plan.

In 1993, Barton-Aschman/PDI found that even dramatic improvements in the bus or público system would not support the necessary travel demand forecasted to occur by 2010. Traffic volumes are expected to increase 45 percent by that date. This report supported the general alignment recommended by the CTA/Alan M. Vorhees study of 1979 (Colucci 1998).

6.1.3 Project Chronology

As seen, support for a rapid rail transit system to serve the SJMA has been growing for some time. It was in 1989 that the Puerto Rico Department of Transportation and Public Works (DTPW) first proposed to construct a light rail transit system called Tren Urbano. A conceptual design was developed at this time. In January of 1993, a team assembled by the newly elected Governor took over the project, and assembled an expert team of mainland US transit professionals and local engineers and architects. This team reviewed the previous work of the DTPW and updated their plans to make Tren Urbano a modern transit system making use of the latest technology, design concepts, and project management techniques. They then successfully lobbied the Federal Transit Administration (FTA) to designate Tren Urbano as one of four turnkey demonstration projects in the United States. These four projects, the Baltimore Light Rail, the San Francisco airport connection, the El Segundo Del Norte Station on the Los Angeles Green Line, and Tren Urbano, were all identified as fitting with the FTA's objectives of advancing new technology, lowering the cost of constructing new transit, and providing examples of the benefits of using the turnkey construction method (GMAEC 1994).

In April of 1994, The DTPW signed a $42 million contract for a General Management and Architectural and Engineering Consultant (GMAEC) joint venture composed of local and mainland firms. This team has since worked with the Highway and Transportation Authority to bring Tren Urbano into fruition. This Tren Urbano Office has been responsible for the project architecture, engineering, and management of the entire process. This included submitting the environmental studies, overseeing the public review periods, obtaining financing from the Federal Transit Administration, and procuring a turnkey contractor to perform the final design, construction, and operations of Tren Urbano.

On July 15, 1996, a $544 million contract was signed between the DTPW and the Siemens Transit Team for the turnkey portion of the Phase I project and on August 2, 1996, the groundbreaking for the project signaled the beginning of the future of transportation in the SJMA (TUO 1997).

6.1.4 Description of Project

Tren Urbano, San Juan's first modern urban rail transit system, is scheduled to open for revenue service in early November 2001. The Phase I project now under construction will serve the three central municipalities of Bayamón, Guaynabo, and San Juan. The population densities within one-half mile of the alignment range from 10,000 to 20,000 people per square mile, and nearly 30% of the total regional employment is within a third of a mile from the alignment. Clearly, Tren Urbano was designed with the ideas of access to jobs and regional mobility in mind (TUO 1997).

This Phase I alignment will be a 17.2 kilometer right-of-way from Bayamón Centro to Segrado Corazón with sixteen stations along the backward C-shaped route. This line will operate twenty hours a day, with a peak headway of four minutes during rush hours. It is estimated that Tren Urbano will serve 115,000 passengers per day and reduce by 50% the number of highway intersections rated at a Level of Service F. Additionally, an estimated 8.78 million hours of travel time will be saved as well as 3 million liters of gasoline annually.

Tren Urbano is a heavy rail transit system operating on a dedicated right-of-way, which includes 9.3 km. of elevated guideways, 6.5 km. of at-grade construction, and 1.4 km. of sub-grade tunnels. The elevated guideway segments are simple-span segmental pre-cast pre-stressed concrete box girders. The tunnel segment is being constructed with a tunnel boring machine and lined with pre-cast concrete sections.

6.1.5 Contracting Strategy

Having qualified under the Federal Transit Administration's turnkey demonstration program, Tren Urbano is being used to demonstrate alternative turnkey, design/build, and construction techniques. The goal is to implement an innovative delivery method that will help to assign risks in such a way that reduces project costs and completion times. *Figure 6-1* shows the organization of Tren Urbano. Essentially, the Tren Urbano Office (TUO) has directly contracted with seven different parties to design, build, and operate Tren Urbano. However, the Siemens Transit Team is ultimately responsible for all design and construction performed by the six design-build contractors.

The turnkey portion of the project, valued at $544 million, was awarded to the Siemens Transit Team (STT), led by Siemens. The scope of this contract includes the design and construction of one segment of the alignment, the construction of the maintenance and storage facilities, the responsibility for design consistency and coordinated systems provision across the entire alignment, and the operation of the transit system for five years, with an option for five more years.

Six other contracts, ranging in value from $33 million to $226 million, have been awarded to six independent contractor joint ventures. The scopes of these contracts include the design and construction of one segment of the alignment each, and are being managed by the Siemens Transit Team.

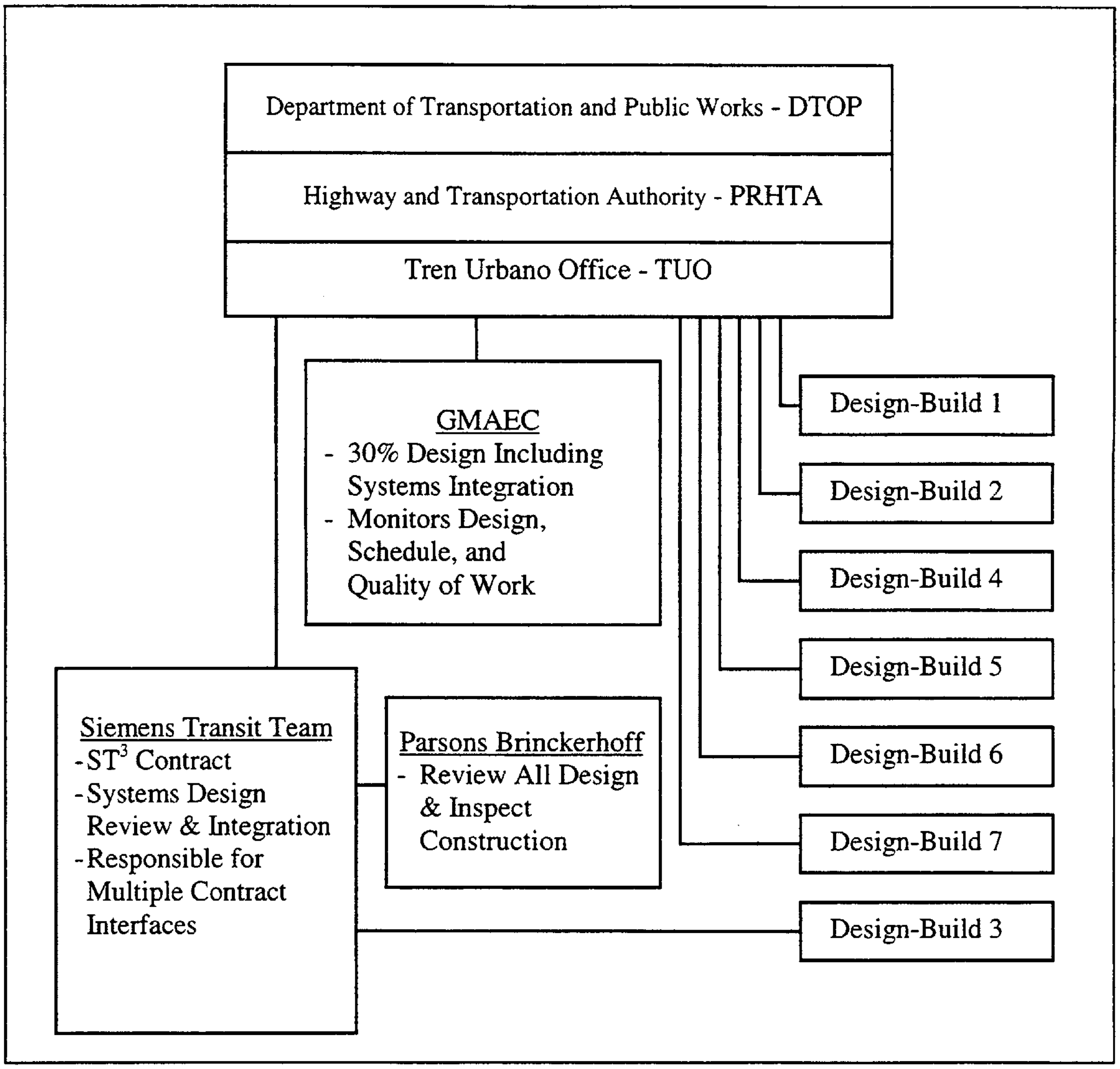

Figure 6-1 Tren Urbano Organizational Structure

This hybrid strategy, being billed a fast-track design/build turnkey procurement, was chosen with many factors in mind. Due to the primary funding source (FTA Turnkey Demonstration Program), the preliminary procurement objective for Tren Urbano is to structure a turnkey program. This approach will allow construction to begin almost two years sooner than under a traditional procurement and will allow the system to begin revenue service by November 2001.

Additionally, several other procurement objectives were identified with regard to Tren Urbano. These objectives include maximizing local participation on the project, bringing transit (design, construction, management, and operations) experience to Puerto Rico, building an expandable system, minimizing risk, utilizing financing techniques that lower the cost of capital, while retaining control over alignment, station planning, and quality of operations (GMAEC 1994).

6.2 Contract Terms with Regard to Infrastructure Management

Expectedly, the ultimate decisions that were made about the procurement of Tren Urbano will have an effect on the long-term performance of their infrastructure assets. Those sections of the contract documents that detail these decisions will be documented below. Unless otherwise noted, all quoted sections are in the **Contract Book II – Operations and Maintenance**.

> **2.1 General**
> "The Contractor shall perform the Services employing the Service Property in accordance with the Contract Documents. The scope of such management, operations and maintenance Services shall include, but not be limited to, those responsibilities set forth in the O&M Documents."
>
> **2.2 Standard of Performance**
> "The Contractor agrees to perform the Services in accordance with the high standards of first class, professional rail transit service providers worldwide, consistent with the transportation policy objectives of the Project, and to use its best efforts to achieve a rail transit system that operates reliable, efficiently, safely and on time, with clean facilities and skilled and courteous personnel."

These two sections of the contract outline the very general obligations charged to the contractor with regard to management and operations & maintenance of the transit system. It is assumed that the contractor will want to perform all services to meet or exceed performance standards as set forth in the contract documents.

> **2.7 System Maintenance**
> "The Contractor shall maintain the Service Property in accordance with the performance standards specified in Section 17010 of the Technical Provisions – O&M, the performance standards specified in Section 4.4, the provisions of the O&M Procedures, and all other applicable provisions of the Contract Documents. Maintenance Services shall include furnishing all labor and utilities and furnishing and replacing all materials, supplies, parts, components and tools and equipment (whether or not the same are provided as a part of the Service Property) necessary to accomplish the proper inspection; cleaning; adjustment; preventive and corrective maintenance; lubrication; repair; testing; replacement of parts and equipment; supplying of spare equipment, consumables and expendables; and repair of spare equipment of all parts of the Service Property and the Project."

"The Contractor shall promptly perform all maintenance and repair obligations as provided in Article 3, including all maintenance and Repairs necessitated by negligence, misuse, accidents, abuse, vandalism, or criminal activities regardless of cause or fault."

The first paragraph of this section outlines the responsibilities of the contractor with regard to maintenance. All performance standards mentioned in this section are only general in nature, and the specific provisions of any standards have yet to be determined. Notice the use of the word 'proper' in this section. The vagueness over what constitutes 'proper' inspection or maintenance can be confusing without the acceptance of specific performance standards.

The second paragraph gives the contractor the impetus to perform all maintenance and repair actions needed regardless of causality or fault. This leads into two other sections that indicate the thinking behind the contract documents. The first is listed below.

3.5.1 Maintenance of Service Property - General
" Subject to the provisions of this Section 3.5 and Section 3.6, below, the Contractor shall keep the Service Property and every part thereof in the same good order, condition and repair as the same were in on the Revenue Service Date..."

This section implies that the entire transit system will be in new condition for at least the next five years. This does not seem reasonable, and it is curious that no "wear and tear" clause is included in this section.

The second is the system of reimbursements for repairs and alterations. **Section 3.5.4 Maintenance of Service Property - Repairs and Alterations** outlines this system, but is too cumbersome to quote at length here. Essentially, the contractor is expected to perform all repairs to the transit system at its sole expense, regardless of cause. The authority will then reimburse the contractor for the cost of such repairs in excess of $25,000. The stipulations vary, but these reimbursements will be given if either the repairs are made necessary solely by the fault of the authority or made necessary as a result of accidental damage. However, "in no event shall the Authority be obligated to reimburse the Contractor for the cost of any Repairs to the Systems or fixed facilities where the need for such Repairs arises in whole or in part from the failure of the Contractor to properly and diligently maintain, secure and protect the Service Property, including performing all preventive maintenance." Again, the use of 'properly and diligently' is not clear, and this phrasing could lead to substantial arguments over the obligation of the authority to pay for repairs.

This clarity is needed in order to begin revenue service. **Section 17020** describes the submittals that must be provided to the authority by the contractor one year prior to revenue service. These submittals are related to all aspects of the transit system's operations, maintenance, administration, and security and are subject to the approval of the authority. Two submittals in particular are important to mention. First, the **Facilities Maintenance Policy and Procedures Manuals** are intended to outline all aspects of facilities maintenance, including inspection and preventive maintenance procedures for all track, structures, and right-of-way facilities. Second, the **Systems Maintenance Policy and Procedures Manuals** are intended to outline all aspects of systems maintenance, including testing, inspection, and maintenance procedures relating to train control, communications, fare collection, and power distribution systems.

While most of the procedures relating to infrastructure management, such as inspection, testing, maintenance, and monitoring, will be outlined in these manuals, the contract documents mention some specific requirements that will affect the development of the manuals. For example, **Section 3.4 Condition of Service Property** and **Section 2.3.8 Reports** states that one month prior to revenue service, "the contractor shall deliver…a detailed and complete inventory of the Service Property including the condition thereof." This does not indicate the format of such an inventory, and should be clarified.

Additionally, the contractor is responsible for an annual report containing "an updated inventory and statement of condition of the Service Property (collectively, an "Inventory") reflecting any additions or capital improvements or other Repairs or alterations made to, and any changes in the condition of, the Service Property." This annual report will also contain documentation "certifying as to the completion and results of all testing, inspections and other activities," while monthly reports "shall contain a specific certification that all preventive and corrective maintenance, inspection, and testing work…was in fact actually performed or completed as directed." This not only implies that regular testing, inspections, and both preventive and corrective maintenance of all infrastructure assets must be performed, but can be interpreted as mandating at least annual inspection and testing of all assets. This is unclear, however.

6.3 Contract Terms with Regard to Infrastructure Management Systems

In **Section 2.3.4 Management Information and Decision Support Systems**, it states that "the contractor shall develop, use and maintain computerized management information and decision support systems to assist in all aspects of performance of the Services (collectively, the MIDSS), operated by skilled professionals using state-of-the-art computerized program management technology...The MIDSS shall receive information from all data collection and transmission systems, including...train control information, turnstile counts, revenue collection information...as well as from the maintenance reporting system, payroll system, inventory system and personnel system." As this is worded, this MIDSS does not appear to be intended as any type of infrastructure management system, yet it does not preclude the inclusion of an infrastructure management system as part of the overall transit management strategy.

A conversation with the contractor that will build the MIDSS indicated that the MIDSS will be compatible with an infrastructure management system developed by the Siemens Transit Team (STT) (Nelson 1998). But no such system is currently under development by the STT (Ferretti 1998). This could lead to system integration problems once the MIDSS is developed and adaptation with any other undefined systems is attempted.

6.4 Analysis of Tren Urbano's Infrastructure Management

To analyze Tren Urbano's implicit program of infrastructure management, two areas must be studied. First, the contracting strategy, or delivery method, should be studied to determine if it provides incentive to the project's participants to consider the effect of their decisions on the entire lifecycle of the project. Since the construction has begun, there could be existing examples of this. Second, the current state of implementation of any type of infrastructure management system must be determined in order to understand the direction being taken.

6.4.1 Contracting Strategy Implications

The contracting strategy was designed with several factors in mind, as stated in *Section 6.5.1.* The end result is a hybrid combination of six design-build contracts and one design-build-operate contract for a duration of five years, with an option for five more years. Two primary issues in this contracting strategy become apparent as they relate to Tren Urbano's program of infrastructure management. First, the coordination between each design-build team could affect the reliability of the entire system. Second, the duration of the operations contract will affect the actions of the design-build-operate team in different ways.

If this contracting strategy were truly composed of several design-build contracts, the implications on Tren Urbano's infrastructure management would be vast. The coordination issues between each design-build team, and between the Siemens Transit Team, which holds the design-build-operate contract, would be quite difficult to overcome. These coordination difficulties would likely translate into differing levels of attention paid to designing for operations. But Siemens is exerting considerable control over the delivery process for operations, and has turned the contracting strategy into what some have called a 'detail-build.' This is meant to imply that such a heavy-handed control over the design process by Siemens has left little for the design-build teams to truly design. This type of control might limit the role of the design-build teams, but it ultimately leads to a more consistent approach to the design, which translates into an easier infrastructure inventory to control.

The length of the operations period could also have an impact on the infrastructure management of Tren Urbano. Under a typical procurement, design and construction would be performed independent of operations & maintenance. This tends to exclude operational concerns from the design and construction process. Under Tren Urbano's procurement, however, the operators are involved in the design and construction process. It was hoped that this integration would cause the design team to consider operational concerns. But the length of the operations period causes some concern.

The obvious argument is that it is not long enough to stimulate design innovations that would affect the long-term performance of Tren Urbano. Five, or even ten, years might not provide Siemens with enough incentive to change their design approach, because operational efficiencies would only appear in a time frame on the order of decades with most of the infrastructure assets. Bridges, for example, age slowly during the first few years after construction, and only begin to show deterioration after several years of heavy use. This concern has been addressed by Jorge Matesanz, who stated that "no change in strategy would occur even if operations period were twenty-five years" (Matesanz 1998). This seems to indicate that Siemens is approaching the design of Tren Urbano with a long-term view. This attitude is refreshing and could indicate that even a short operations period can affect long-term changes in project delivery.

But an additional concern related to the length of the operations period is the maintenance concern. Will Siemens maintain the transit system with only five, or possibly ten, years in mind? At the end of the contracted operations period, in what condition will the transit system be? These are legitimate questions. The procurement and contracting strategy have attempted to address this. Section 3.5.1 of Book II – O&M mandates that the transit system shall be kept in an optimum state of service throughout its life. While this clause has some dubious wording with respect to normal deterioration, it speaks to the fact that Siemens cannot simply neglect the transit system at the end of their operations period and must turn the system over in a condition expected of a five, or ten, year old system.

6.4.2 Current Status

In terms of actual evidence that operational concerns are being addressed in the design of Tren Urbano, it appears to be occurring on at least a limited basis. One example is the design of access panels for inspection of the concrete box girders of the elevated guideways. According to several sources, the placement of the panels was made according to the wishes of the future operators of Tren Urbano. This placement contradicts typical design standards, but was made due to the operational concern placed on safe and efficient access to the interior of the concrete box girders.

As of this point, little, if any work has been done on preparing an infrastructure management process for Tren Urbano. No work has been done on either the **Facilities Maintenance Policy and Procedures Manuals** or the **Systems Maintenance Policy and Procedures Manuals**. No attempt to develop an infrastructure management system has begun (Ferretti 1998). This may or may not be distressing considering the fact that the system is not due to open for revenue service for another three years. Regardless of this, as much attention should be paid during the design and construction phases as is possible to long-term concerns. This will help to ensure smooth and efficient operations ten, thirty, or fifty years from now.

6.5 Application of Industry Research and Survey Results to Tren Urbano

6.5.1 General Findings

The primary lesson that is learned from the industry research and survey results is the need to begin any infrastructure management plans at the beginning of infrastructure service provision. Several transit agencies identified early system development as crucial to the entire process.

Paulson's influence curve (See *Figure 2-1*) reinforces this concept by showing how the ability to control the costs of implementing effective infrastructure management decreases with increasing time. To this concept is added the graph shown in *Figure 6-2*, which shows the increasing difficulty of implementing effective infrastructure management with increasing time. Once the operations & maintenance phase of an infrastructure system begins, it becomes increasingly difficult to identify assets, implement inspection schedules, and change employee habits without a large investment and a time-consuming commitment.

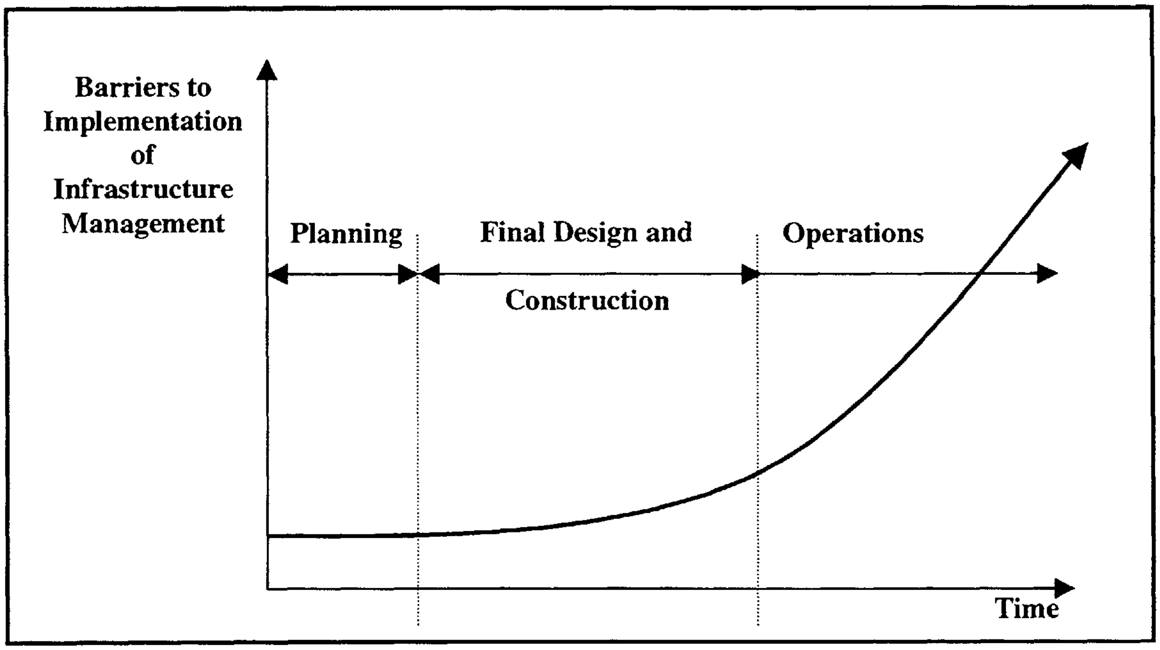

Figure 6-2 Barriers to Implementation of Infrastructure Management

6.5.2 Inspection Findings

Inspections are seen to follow a fairly consistent frequency among transit agencies. Typically, bridges, tunnels, and stations are inspected on intervals of two years. Some use other frequencies, such as the New York City Transit Authority (NYCTA), which inspects all structural elements annually, or the Baltimore Mass Transit Authority (BaltMTA), which inspects tunnels and stations every five years. But most, regardless of age, utilize biennial inspection frequencies for all structural infrastructure assets. Tren Urbano would do well to implement a biennial visual inspection schedule for all structural elements. Although the contract might seem to indicate that annual inspections are mandated (Section 6.2), this is not totally clear. At least during the first ten years of operation, a more aggressive inspection schedule might not utilize inspection funds in an efficient manner.

Track inspections are typically done at least once a week. The frequency varied with each agency. Some visually inspect their track twice or three times a week, while some agencies inspect track every two weeks. This frequency is not related to the use of other non-visual inspection methods, which most agencies mentioned using. No reasons were cited as to the selection of track inspection frequencies, but it is assumed that the nature and function of track infrastructure assets necessitate a high frequency of inspections. Tren Urbano should therefore implement visual track inspections at a frequency of at least twice a week. Other non-visual methods should be used to enhance visual inspections.

System inspections, for assets like power, signaling, or communications, are too specific to identify trends for inspection, and will vary from agency to agency, or system type to system type. Tren Urbano should identify manufacturer specifications and industry standards when scheduling system inspections.

6.5.3 Management System Findings

The use of management systems in transit is growing, and most transit agencies understand the importance of using infrastructure management systems. From being an 'irreplaceable function for maintenance,' to being a 'useful tool in developing capital budgets,' agencies understand the benefits to be gained from using infrastructure management systems. They cite that these systems are the 'best way to follow the deterioration;' they 'save time, save headaches, and prevent problems;' they 'reduce costs, help to control assets, and help to manage inspection.'

Essentially, these agencies know the positives to be gained from the implementation of an effective infrastructure management process. But how many of them understand the costs that are entailed in developing these systems? Six of the eight agencies answered yes when asked if they use an infrastructure management system. But none of them could answer when asked to describe the costs associated with implementing or maintaining their infrastructure management system. This is a very telling statistic. Similarly, six of the eight (not the same six) could not provide the breakdown of their inspection budget. This inability to identify their own costs indicates that they are unable to control these costs. This suggests that their management systems are not being utilized correctly, because cost identification and control should be emphasized heavily throughout the process.

Tren Urbano's infrastructure management system must enable operators, engineers, and managers to identify detailed costs of service provision, because these actual costs form the basis of maintenance programming and capital planning. To achieve this, Tren Urbano is urged to implement a modern infrastructure management system based on the recommendations of the following section.

6.6 Recommendations

The ultimate goal of any infrastructure management strategy should be to minimize the lifecycle costs associated with providing transit services. After realizing this point, a detailed strategy can be devised which will achieve this goal.

The basic strategy will be to develop the infrastructure management process for Tren Urbano based on the eight steps of the Infrastructure Management QuickTest. This recommendation has a dual purpose. First, the Siemens Transit Team (STT) can utilize these recommendations when designing the process. Second, the Tren Urbano Authority (TUO) can use these recommendations when evaluating the process proposed by the STT as part of the Policy and Procedures submittals specified in **Section 17020** of the Contract Documents.

As described in chapter 5, this process has the following eight primary characteristics. Each is important to the entire process. Within each eight are specific recommendations for developing an infrastructure management process that will comply with the QuickTest.

6.6.1 Data – Network

1. Establish your inventory through a complete system-wide assessment of your capital assets. Because the contractor is required to deliver an inventory and condition assessment of all infrastructure items to the Authority (See Section 6.2 above), this provides a great opportunity for both parties to ensure that an initial inventory database is built and used. *Figure 6-3* provides a suggestion on asset breakdown on which to base database design. **Note: For most effective results, integrate all infrastructure asset data into one inventory database.**

Asset Type
1. Vehicles Revenue Vehicles Non-Revenue Vehicles

2. Fixed Facilities
Buildings
Rail Infrastructure
    Track
    Structures – Bridges/Tunnels/Stations

3. Equipment
Maintenance Equipment
Systems
    Fare Collection
    Communications
    Signaling/Operations

Figure 6-3 Potential Asset Groupings (LSTS 1996)

2. Identify key components of each type of asset, and the relationships between each asset. In many cases, industry standards exist for these components. Bridges, or elevated guideways, for example, can easily be defined in terms of their Federal Highway Administration (FHWA) core elements.

3. Identify all possible condition/performance states and provide clear definitions of each. *Figure 6-4* provides a graphic representation of a condition/performance matrix. This generic matrix can be used to plot the condition and performance of each asset and determine appropriate strategies for dealing with each condition/performance state. The matrix shown consists of five condition/performance states, but this is highly dependent upon individual agency preferences.

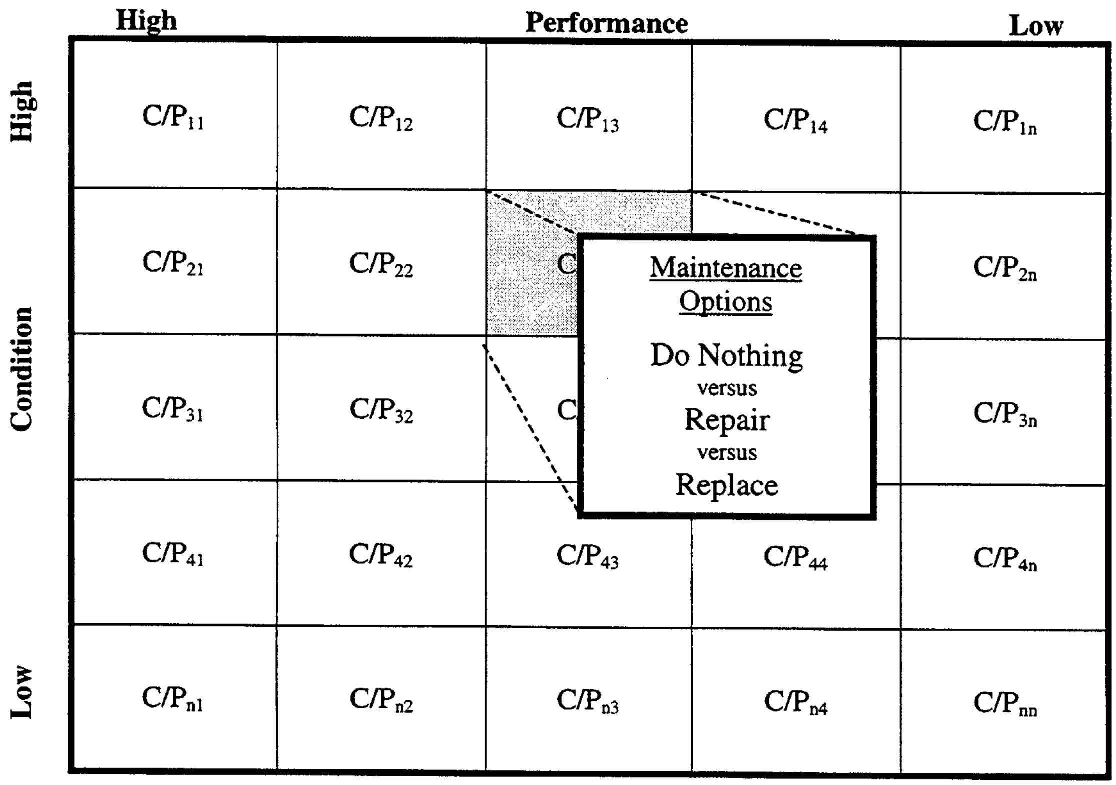

Figure 6-4 Suggested Condition/Performance (C/P) Matrix

4. Use computer technology (i.e. databases) to store all inventory and subsequent data. Manage data in accordance with usage (i.e. All participants have access to all and only data they require).

5. Locate all assets using a coordinated system-wide referencing system that takes into account all asset types. The transit right-of-way provides a useful linear-based reference system to locate and identify all asset types.

6.6.2 Data – Industry

1. Identify all potential maintenance actions for all components for all condition/performance states. Allow flexibility for new technologies. Each asset in each condition/performance state (C/P_{xy}) has a number of different maintenance options, represented in *Figure 6-4* as Do Nothing, various Repair options, and Replace. Allow flexibility for introducing new maintenance options and new technologies.

2. Tap into industry and in-house technical knowledge to estimate the expected lifecycle costs and benefits of each maintenance action on each component for each condition/performance state. For instance, for an asset in C/P_{23}, doing nothing will have a certain lifecycle cost or benefit associated with it, and each repair or replace option has certain lifecycle costs and benefits associated with them. Knowing these costs and benefits will allow appropriate comparisons to be made later in the process.

3. Again, tap into industry and in-house technical knowledge to estimate the expected condition/performance state results of each maintenance action on each component for each condition/performance state. For instance, for an asset in C/P_{23}, doing nothing might cause the asset to deteriorate to C/P_{44}. Similarly, each repair option might cause the asset to improve in both condition and performance, perhaps to C/P_{12}. Finally, replacing an asset should cause that asset to return to C/P_{11}.

6.6.3 Needs – Current

1. Implement aggressive inspection program to identify condition/performance states of all assets. Repeat regularly and as needed. See Section 6.5.2 for inspection recommendations.

6.6.4 Needs – Future

1. Determine modeling approach to predict remaining service life based on current and historical condition/performance states and known policy or budget constraints. This is a highly specific process that should be investigated. The choice between deterministic or probabilistic modeling must also be made.

2. Model deterioration based on both condition/performance states and predicted maintenance policies and budgets. Assess the likelihood of various C/P states over time.

6.6.5 Alternatives

1. Simulate alternative effects of different policy choices and budget allocations on maintenance actions. Use these results to determine the effects of each maintenance action on (a) deterioration rates, (b) service lives, (c) lifecycle costs, (d) budget constraints, and (e) each of these over the entire network of assets.

6.6.6 Programming

1. Optimize results of alternatives analysis with respect to lifecycle costs. Select projects that minimize the lifecycle cost of providing the desired level of transit service. Schedule and budget for necessary maintenance actions.

6.6.7 Feedback (Integration)

1. Establish communication between various project participants to allow for feedback and discussion of potential future options.

2. Identify actual costs and benefits of programmed actions for future predictions and to support planning process.

3. Ensure that all required information is being collected by and disseminated to the proper project participants. Identify better data reporting methods that better support the entire process of infrastructure management.

4. Discuss changes in project delivery with all project participants to understand how integration could help.

6.6.8 Influence (Capital Budgeting)

1. Identify the implications of repair vs. replace decisions and work to ensure that the most economical choices are being made to provide a desired level of transit service.

2. Analyze the choices being made with respect to project delivery method to determine if the most economical choices are being made.

3. Adapt the process to reflect new knowledge.

6.6.9 Infrastructure Management System Design

Sections 6.6.1 through 6.6.8 give specific recommendations for the development of an infrastructure management process. Implied in these recommendations is the development of an infrastructure management system to support this process. While it is difficult to recommend specific system characteristics, due to some very specific needs of Tren Urbano's operators, there are some general attributes that an effective system must have.

First, an infrastructure management system should be complementary to the organization that is using the system. It should reinforce the entire infrastructure management process and have an intuitive relationship with the organizational structure of the transit agency. This also implies user-friendliness of the system so that the necessary participants utilize the system. Second, the infrastructure management system should be built so that easy access to all relevant data and information is available to all participants. Each participant, such as public officials, transit managers, or maintenance engineers, has different data needs. The system should recognize the level of detail that each participant needs in order for the system to be useful to that participant. Third, an underlying assumption of an infrastructure management system is that it can effectively monitor costs and be used to evaluate alternative actions based on lifecycle costs. Tren Urbano's infrastructure management system must be able to do this to support the entire infrastructure management process. This includes the needs of future planning, which must be considered if the infrastructure management system is to perform as expected.

Essentially, an infrastructure management system should support and perform the level 1 and level 2 tasks described in chapter 5, and support the level 3 decision-making process.

6.6.10 Organizational Capacity and Support

Finally, it is imperative that the infrastructure management process receives the necessary organizational support needed to be successful. This is a very generalized comment that speaks to the organizational commitment towards infrastructure management. It must be a full-time concern of the entire agency to minimize the lifecycle costs of providing infrastructure services. Organizational support provides the foundation for all other aspects of infrastructure management. This translates into a need for managerial and funding support of those activities that further the agency's objectives of infrastructure management.

6.7 Summary

This chapter summarized the current situation of infrastructure management for Tren Urbano. It is seen that the planning and political environment impacted the project procurement in such a way that is relatively beneficial. Design, construction, and operations were combined under the umbrella responsibility of one private sector participant. This provides the incentive to consider the lifecycle implications of all decisions during design and construction. However, the relatively short operations period (5 years) could act to negate this in at least a limited manner. But the procurement does have many benefits, and gives all participants the incentive to work towards effective infrastructure management.

Also discussed in this chapter were recommendations that could assist in the development of an operational infrastructure management process for Tren Urbano. These recommendations are based on the assumption that Tren Urbano is looking to minimize the lifecycle costs of providing transit services. These recommendations follow the steps discussed in chapter 5 that were found to be necessary to implementing effective infrastructure management. Keeping in mind that several of these recommendations are more specific than others, it should be noted that specifics were given only as examples that support the general concepts of effective infrastructure management.

7 Conclusions

7.1 General Review

This thesis has developed the idea that effective infrastructure management is an on-going process involving all phases of the infrastructure lifecycle. It makes sense that decision-making should reflect this long-term view. Choices encountered in the planning, design, and construction phases of a project should be addressed with the goal of minimizing lifecycle costs of service provision. Because the traditional model of infrastructure management does not provide the proper incentive to do this, a new model is needed.

Additionally, the current status of our infrastructure 'crisis' has necessitated the use of a new approach to the financing, delivery, and management of infrastructure. As the US Advisory Commission on Intergovernmental Relations (USACIR) concluded in their report to the President, "America's infrastructure is barely adequate to fulfill current requirements, and insufficient to meet the demands of future economic growth and development." This significant finding tends to support the 'doomsday' statistics cited in chapter 1 (USACIR 1993).

To change this impending reality, several strategies have been offered. Some researchers have argued that more money, more innovations, or increased efficiency is needed, but these solutions offer few pragmatic answers, only directions. More useful has been the development of new tools in two distinct, yet related, areas of infrastructure management. Integrated delivery methods and infrastructure management systems offer the potential to improve the performance of infrastructure. Because each method is fundamentally based on lifecycle costs, a desirable level of service can be reached at a minimum lifecycle cost.

Infrastructure management systems track deterioration and predict future maintenance needs. It is therefore possible to use these predictions to develop trial cash flows for future projects. These cash flows allow an owner to earmark funds in future budgets and to evaluate alternative delivery options for operations & maintenance of existing facilities and development of new facilities. Ultimately, this new approach dictates that infrastructure owners know the detailed costs of providing infrastructure services so that new methods of providing these services can be compared. The intended result should be sustained, incremental improvements in long-term performance of infrastructure gained from an explicit understanding of the trade-offs in quality and lifecycle costs inherent in these improvements.

7.2 Specific Recommendations to Infrastructure Owners

7.2.1 New Approach

To achieve incremental improvements to infrastructure performance, owners must approach infrastructure management from a different perspective. With an ultimate goal of minimizing the lifecycle costs of providing infrastructure services, this new perspective must focus on combining the efforts of condition/performance assessment for proposing capital budgets with the efforts to utilize alternative delivery methods. This combination has the dual purpose of bringing cost data into the process of infrastructure management while providing incentive to consider lifecycle costs.

It is possible to combine these efforts by utilizing the inherent cohesiveness between integrated delivery methods and infrastructure management systems, shown in *Figure 2-3*. As shown, the incentive provided by integrated delivery methods to consider lifecycle costs can lead directly to the use of an infrastructure management system. More importantly, the ability to use infrastructure management systems to monitor actual costs of infrastructure service provision provides decision-support to the planning process.

7.2.2 Iterative Process of Decision-Making

The new approach will allow owners to set up a systematic process for evaluating the most crucial of maintenance decisions (Repair vs. Replace), and allow them to align their financing methods to support this process. Of course, this decision is ultimately based on a comparison of lifecycle costs of the various alternatives.

This approach is based upon the fact that at every time during the lifecycle, the choice to act (Do Nothing, Repair, Replace) can be considered based upon the future lifecycle cost comparison between not acting and acting in multiple ways. The latter two options (Repair, Replace) could each include multiple sub-options utilizing different technologies or delivery methods, each with their own lifecycle cost, among other, implications. The goal is to provide the desired level of service for a minimum lifecycle cost.

The following *Figure 7-1* illustrates this decision. At the time indicated by the vertical dotted line, the choice to Do Nothing (Option 1), Repair (Option 2), and Replace (Option 3) is given. Option 1 will simply continue the cost trends as determined by monitoring prior service. Option 2 involves a slight cost increase to account for the repair work, under the assumption that service costs will decrease. Option 3 involves a more substantial cost increase to account for the replacement, under the assumption that service costs will decrease substantially. Basing future service costs and increases on previous trends and known costs allows a realistic lifecycle cost to be developed for each option.

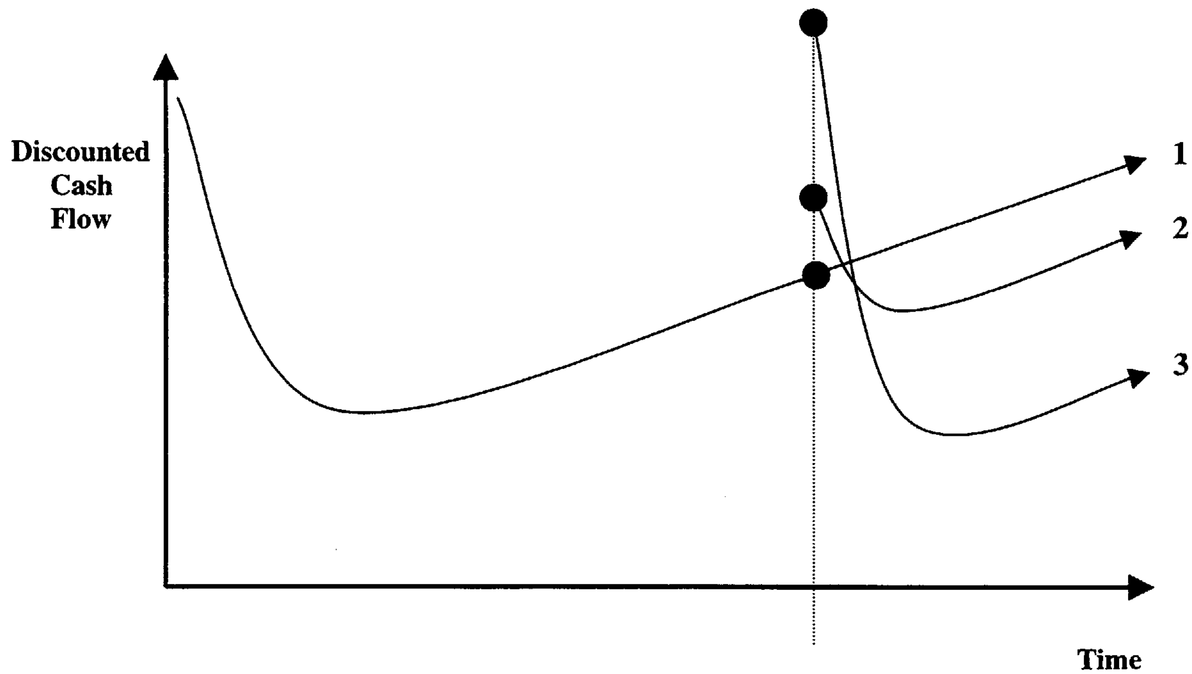

Figure 7-1 Discounted Cash Flow Projections

An iterative model defines the cost development of this process. This iteration takes place continually over the entire lifecycle of the infrastructure asset network, with owners continually comparing their present delivery of infrastructure services with new options in both technology and delivery method. The decision to alter the present delivery of infrastructure services should be based on the best future lifecycle costs, and should not consider sunk costs or predicted life spans if new methods render current methods obsolete.

Essentially, the following three steps in the iteration show a change in approach to the delivery of infrastructure. Owners should perform the planning, design, and construction phases of the lifecycle with a consideration of future operations & maintenance costs. But this should be done with the knowledge that future methods, technologies, and needs will change and force owners to reconsider the lifecycle implications of their decisions continually throughout the lifecycle. This is indicated by the following three steps that owners must follow.

- **Prediction of operations & maintenance costs.**
  When new facilities are being planned and designed, future operations & maintenance costs for that facility must be assessed, and the requisite need for future expenditures must be identified. Delivering projects using integrated delivery methods gives an owner incentive to predict these future cash flows.

- **Monitoring/measuring of actual operations & maintenance costs.**
  During service, actual costs of operations & maintenance procedures should be collected in such a way that comparisons to similar work can be made. Unit costs would be appropriate for most cost data. Infrastructure management systems, properly utilized, can effectively monitor and evaluate this cost data.

- **Adjustment of estimates and procedures to reflect new data.**
  This collected data must then be analyzed to understand the implications behind the agency's cost behavior. This data can be used to update predictions for new construction, and can be used to identify areas of improvements in maintenance. Additionally, alternative delivery methods and innovative technologies can be compared to determine minimum lifecycle cost options.

These three steps, in *Figure 7-2,* show how the Repair vs. Replace decision can be approached. At any time in an infrastructure asset's lifecycle, the decision to either Do Nothing, Repair, or Replace the asset should be considered. Basing this decision on lifecycle costs is simply a matter of comparing the known costs of previously undertaken actions with the predicted costs of new or innovative actions. These predicted costs can be controlled through a competitive bid.

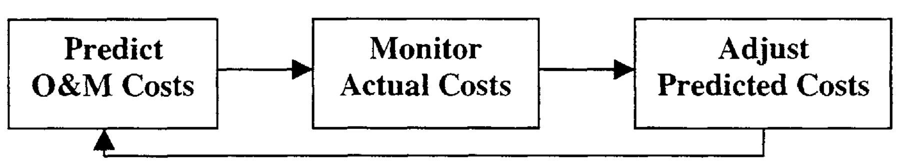

Figure 7-2 Iterative Model of Decision-Making

7.2.3 Additional Benefits of New Approach

Aside from Repair vs. Replace, this approach will also support other decisions throughout the lifecycle of an infrastructure asset network. Decisions that were previously made within a limited factual background can now be gauged and quantified according to actual data. Examples of these types of decisions that will be supported by accurate cost data can be found throughout the lifecycle of a project and are illustrated below in *Figure 7-3*.

Infrastructure Lifecycle Phases				
Planning	**Design**	**Construction**	**O&M**	**Renewal**
1. Build versus Don't Build 2. **Choice of Delivery Method**	1. Technology Choices 2. Choice of Capacity or Size	1. Choices of Construction Methods	1. **Maintenance Options (Repair vs. Replace vs. Do Nothing)**	1. Renewal Options (Retire vs. Reuse vs. Demolish)

Figure 7-3 Decisions Supported by Accurate Lifecycle Cost Data

The two highlighted decisions have been dealt with more specifically in this thesis. The choice of delivery method, made during the planning phase, can be influenced directly by understanding the discounted lifecycle cash flows associated with alternative delivery methods. Likewise, the choice of maintenance performed on an asset can be influenced by the lifecycle costs associated with each alternative maintenance option. Knowing actual costs from previous projects can be quite valuable as a means to compare new and old methods and technologies.

The particular case of maintenance options presents other challenges as well. First, too often the choice between repairing an asset and replacing an asset is based upon factors unrelated to lifecycle cost considerations. This is primarily due to the distinction drawn between capital spending (replace) and recurrent maintenance spending (repair). Capital spending is typically seen in a different light than maintenance spending. Different budgets for maintenance spending and capital spending reinforces this difference. Owners would be wise to recognize that capital spending and maintenance for infrastructure are the same, and therefore equally important investment methods. Spending decisions should then be based on minimized cost of service provision, not dependent on budget distinctions.

7.3 Future Directions

This thesis has developed a new model of infrastructure management based upon the integration of two independent strategies: Integrated Delivery Methods and Infrastructure Management Systems. These two strategies form a mutually supportive basis for decision-making based on lifecycle cost considerations.

In order to more fully develop these ideas, a number of areas would need to be pursued further. Several suggested areas of future research include the following.

- **Quantitative Analysis of the Effects of Delivery Methods on Infrastructure Management**
  A study that attempted to quantify the lifecycle costs associated with various delivery methods, based on level of service provided, type of maintenance actions performed, or type of infrastructure assets owned, could be very useful. This type of analysis would provide more insight into the actual effects that the choice of delivery method could have on lifecycle costs.

- **Development of an Integrated Management Systems/Capital Budgeting Program**
  Attempting to develop a computerized system that performed the tasks of infrastructure management and utilized the results of these tasks to identify an optimum capital budget would be a difficult, yet relevant next step. The technical challenge associated with this process could help to identify better methods of data management and information flow.

- **Data Management for Variable Infrastructure Subsystems**
  The differences inherent in each infrastructure type (transit, bridges, sewers, telecommunications, etc.) needs to be further explored. The specific microscopic aspects of each infrastructure type has an effect on the macroscopic integration of such things as location referencing, benefit calculations, and present worth.

Appendix A - Definitions

In Chapter 1, various definitions of infrastructure have been given based on viewing infrastructure as a collection of either physical assets or services, or viewing infrastructure as defined by what type of entity controls those assets and services. However, as this thesis is concerned primarily with infrastructure of an urban rail transit system, the following definitions will be used.

Infrastructure Assets: All fixed facilities and Systems of a rail transit system, as defined below.

Infrastructure Management: The sum of the decisions, policies, and practices that are adopted with respect to the delivery of or the maintenance applied to any infrastructure asset or network of assets.

Infrastructure Management System: The operational package (methods, procedures, data, software, policies, decisions, etc.) that links and enables the carrying out of all the activities involved in infrastructure management.

Service Property (TU Contract Book II): The fixed facilities and the Systems, together with all other land, structures, improvements, materials, tools, equipment, inventory and other real or personal property (including computer software and other intellectual property) constituting the Project, or used in the operation and maintenance of the Project, whether now existing or hereafter acquired or constructed.

Fixed Facilities (TU Contract Book II): All fixed structures and improvements required to be furnished, constructed or installed under the Contract Documents and the Alignment Section Contracts that will be permanent improvements to the Site, including, without limitation, guideway structure(s), tunnels, stations, parking facilities, equipment rooms, vehicle maintenance and storage facilities, the central control facility, administrative offices and all other improvements to be constructed or installed on, over or under the Site.

Systems (TU Contract Book II): The vehicles, track work, switches, contact rail, other guideway equipment, traction power, power distribution systems, operations control center system, train control systems, communications systems, fare collection equipment, escalators and elevators and all other support systems, materials and equipment associated with operating the Project, as required by the Contract Documents.

Project (TU Contract Book II): The portion of Tren Urbano that includes the Work, the work to be performed by the Alignment Section Contractors, and all Other Work, which, collectively, constitute the approximately 17 kilometer rail transit system from Bayamón to Santurce, Puerto Rico.

Appendix B - Infrastructure Management Transit Survey

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE, MASSACHUSETTS 02139-4307

Date

General Manager
Transit Agency
Street Address
City, State, ZipCode

Re: Infrastructure Management

Dear General Manager:

I am researching infrastructure management policies employed by urban rail transit agencies around the world. I would greatly appreciate your assistance in taking the time to complete the attached survey and providing me with any relevant data or information about the Transit Agency. This information will be used to recommend an optimum policy of infrastructure management for the urban rail transit system being constructed in San Juan, Puerto Rico (Tren Urbano).

The term "Infrastructure Management System (IMS)," for the purposes of this research, is considered as any activity that coordinates and integrates the essential functions of inspection, inventory, maintenance and repair and rehabilitation, life assessment, engineering knowledge, budget considerations and decision-making in order to optimize limited resources across all infrastructure elements.

I am particularly interested in determining what types of systems and policies are currently being utilized to manage the infrastructure elements of your urban rail transit agency, and the effectiveness of those systems for your agency's particular situation. My intent is to provide recommendations of infrastructure management policies and practices to Tren Urbano that are directly applicable to a new urban rail transit agency. This, and other associated work, will provide the basis for my Master's thesis at MIT.

I would greatly appreciate receiving the completed survey by Return Date. In return for completing the survey, I will gladly share the results with your agency. If you have any other questions or confusion about this survey, please contact me. If you feel that another member of your organization would be able to provide more assistance, please pass this letter and survey along to them, and e-mail me their name and address. I will contact you in approximately one week to answer any questions that may have arisen. Thank you for your assistance.

Sincerely,

Daniel A. Zarrilli
Rm. 1-050
Phone: (617) 253 – 9736
Fax: (617) 258 – 5942
Email: daz4@mit.edu

Cc: Prof. Nigel H.M. Wilson
Prof. John B. Miller

Control Number | Transit Agency

SURVEY NOTES & DEFINITIONS

1. Intent: This survey is intended to capture the policies and practices of your rail transit agency with respect to infrastructure inspection and infrastructure management. If the questions asked do not adequately capture your agency's methods or strategies, please attach whatever documentation would be necessary to describe your policies and practices.

2. Scope: All information should pertain to your agency's urban rail operations, both Heavy Rail and Light Rail.

3. Structures: Defined as all revenue and non-revenue structural elements, including elevated guideways, bridges, tunnels, and stations of the transit agency.

4. Track: Defined as all revenue and non-revenue rail of the transit agency.

5. Systems: Defined as all revenue and non-revenue electrical and mechanical systems of the transit agency, such as signal systems, control systems, power systems, etc. of the transit agency.

6. Substructure: Defined as any element of an elevated guideway or bridge, such as piers, abutments, or arches, used to carry load from the superstructure to the foundation. In this survey, quantities of substructure elements are defined as quantity measures. For example, any bearing point of the elevated guideway, whether a pier wall, multiple columns, or an abutment shall equal 1 EA (each) of substructure.

7. Superstructure: Defined as any element of an elevated guideway or bridge, such as beams, girders, stringers, trusses, decks, or slabs used to carry load to a substructure element. In this survey, quantities of superstructure elements are defined in length. Only centerline distances are requested. For example, an elevated section of track supported by multiple steel girders and a floorbeam system for 1.2 miles shall equal 1.2 miles of superstructure.

8. Inspections: *Superficial Inspection/Casual Observation*: Informal assessment of structural elements by technical or non-technical personnel at irregular intervals.

   Principal Inspection/Full Visual Investigation: Typical method of structural inspection performed at regular intervals by trained inspection personnel.

   Special Inspection/Full Structural Evaluation: Comprehensive evaluation of structural capacity, usually performed at longer intervals.

Daniel A. Zarrilli

MIT – Civil and Environmental Engineering
daz4@mit.edu 77 Massachusetts Ave. Rm. 1-050 Cambridge, MA 02139Fax: (617) 258-5942

Control Number | Transit Agency

GENERAL INFORMATION

Please answer all questions. Indicate if an item is not appropriate by marking N/A. Also feel free to attach additional sheets in order to answer all questions accurately. Thank you.

Please print or type all responses.

Transit Agency Name: ______________________________.

Region or City Served: ______________________________.

Years of Operation: ______________________________.

Type of Organization (Circle One): **Public** **Private** **Other** ______________

____

____.

Budget (US$ 1997):

Total Annual Urban Rail Operating Budget: $______________.

Annual Maintenance Budget: $______________.

Annual Inspection Budget: $______________.

Contact for Additional Information:

Name / Title: ______________________________.

Address: ______________________________.

Phone / Fax: ______________________________.

E-mail: ______________________________.

Control Number

Transit Agency

STRUCTURAL INFORMATION

Elevated Guideways (Including Bridges):

Total Length of Elevated Guideways: ______________________ **Miles.**

Main Structural Material:	**Substructure**[6]	**Superstructure**[7].
Reinforced Concrete:	_______ **EA.**	_______ **Miles.**
Pre-Stressed Concrete:	_______ **EA.**	_______ **Miles.**
Post-Tensioned Segmental Concrete:	_______ **EA.**	_______ **Miles.**
Steel:	_______ **EA.**	_______ **Miles.**
Timber	_______ **EA.**	_______ **Miles.**
Other (Specify): ______________	_______ **EA.**	_______ **Miles.**

Typical Span Type (Circle One): **Simple-Span** **Continuous,** _______**Spans.**

Tunnels:

Total Length of Tunnels: ______________________ **Miles.**

Main Structural Material of Tunnels:

Reinforced Concrete: ______________________ **Miles.**

Prestressed Concrete: ______________________ **Miles.**

Steel: ______________________ **Miles.**

Timber: ______________________ **Miles.**

Other (Specify): ______________ ______________________ **Miles.**

Stations:

Number of At-Grade Stations: ______________.

Number of Elevated Stations: ______________.

Number of Sub-Grade Stations: ______________.

Total Linear Feet (LF) of One-Way Track at Station Platforms:______________ **LF.**

Control Number		Transit Agency

STRUCTURAL INFORMATION

Trackwork:

Total Length of At-Grade One-Way Track: ______________________ **Miles.**

Total Length of Elevated One-Way Track: ______________________ **Miles.**

Total Length of Sub-Grade One-Way Track: ______________________ **Miles.**

Typical Tie Material (Circle One): Timber   Concrete   Other______________.

Structural Age (Years):	**<u><5</u>**	**5-20**	**21-50**	**51-100**	**>100**
Miles of Elevated Guideways:	______	______	______	______	______.
Miles of Tunnels:	______	______	______	______	______.
Number of Stations:	______	______	______	______	______.

Please use the space below to explain any distinctive track or structural features that would help to provide a clearer indication of your fixed facilities network, including aspects that impact your choice of inspection/maintenance strategies.

Daniel A. Zarrilli   MIT – Civil and Environmental Engineering
daz4@mit.edu   77 Massachusetts Ave. Rm. 1-050 Cambridge, MA 02139Fax: (617) 258-5942

Control Number Transit Agency

INFRASTRUCTURE INSPECTION POLICIES

Typical Structural Inspection Interval (Years):	**Elevated Guideways**	**Tunnels**	**Stations**
Superficial Inspection/Casual Observation[8]:	______	______	______.
Principal Inspection/Full Visual Investigation[8]:	______	______	______.
Special Inspection/Full Structural Evaluation[8]:	______	______	______.

Typical Track Inspection Intervals (Please Describe): ________________________________

____

____.

Typical Systems[5] Inspection Intervals (Please Describe): ________________________________

____

____.

Inspection Team (Education or Training):

Qualifications of Structural Inspectors: ________________________.

Qualifications of Track Inspectors: ________________________.

Qualifications of Systems[5] Inspectors: ________________________.

Inspection Methods/Manuals (Standardized Procedures Used During Inspections):

Structural Inspection Procedures: ________________________.

Track Inspection Procedures: ________________________.

Systems[5] Inspection Procedures: ________________________.

Estimated Inspection Budget:	**Track**	**Elevated Guideways**	**Tunnels**	**Stations**
1997 $US/LF:	____	______	______	______.

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INFRASTRUCTURE MANAGEMENT POLICIES

Use of Infrastructure Management System (Circle One): Yes No

If Yes:

Activities Coordinated by Infrastructure Management System (Check All That Apply):

Comprehensive Structural Inventory: ______

Comprehensive Track Inventory: ______

Comprehensive Systems[5] Inventory: ______

Standardization of Components/Elements: ______

General Inspection Planning: ______

Inspection/Testing Reports and Records Archival: ______

Maintenance/Repair Recommendations: ______

Cost Estimation of Maintenance Options: ______

Modeling of Deterioration Rates: ______

Optimization of Limited Fund Allocations: ______

Network-Level Decision-Making: ______

Other: ____________________________ ______

Department Responsible for Usage and Maintenance of the System?

____

Departments Given Access to the System and for What Purpose?

____

____

____

____

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INFRASTRUCTURE MANAGEMENT POLICIES

Please describe your agency's use of your infrastructure management system and it's importance to the various departments that use the system.

Please describe the costs associated with implementing/maintaining your infrastructure management system.

Please describe the benefits associated with implementing/maintaining your infrastructure management system.

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Control Number Transit Agency

INFRASTRUCTURE MANAGEMENT POLICIES

Please describe, if possible, your agency's history with infrastructure management systems, including earlier attempts, results, and any recent developments.

Please provide your opinion/experience on the usefulness or cost-effectiveness of utilizing an infrastructure management system in an urban rail transit agency.

Please provide your opinion/experience on the usefulness or cost-effectiveness of implementing an infrastructure management system immediately after construction of an urban rail transit system.

If Your Agency Does Not Use Any Infrastructure Management Systems, Please Indicate the Reasons:

____

____

____.

Please use this space to comment on any item that you feel needs elaboration in order to give a clearer picture of your inspection/maintenance and infrastructure management policies, including any site-specific concerns or innovative strategies you've encountered. Additionally, please attach any additional information that you feel may be relevant to this study. This could include any cost-benefit assessments or similar studies performed to gauge the effectiveness of your inspection/maintenance or infrastructure management policies.

Your Name: ______________________________________.

Best Reached at: ______________________________________.

Thank you for all of your time and effort in completing this survey.
Please return to:
Daniel A. Zarrilli
MIT Rm. 1-050
77 Massachusetts Ave.
Cambridge, MA 02139 USA

Appendix C - Infrastructure Management QuickTest

Infrastructure Management QuickTest

Check Box if Question Can be Easily Answered:

Data – Network

1. What infrastructure assets do we own? ☐
2. What is the geographic location of these assets? ☐

Data – Industry

1. What MR&R options are available to our network of assets? ☐
2. What costs and benefits are associated with these options? ☐
3. What action effectiveness is gained from these options? ☐

Needs – Current

1. What is the current condition of each infrastructure asset? ☐
2. At what performance level is each infrastructure asset? ☐

Needs – Future

1. What is the remaining design service life of each asset? ☐
2. At what rate is each infrastructure asset deteriorating? ☐

Alternatives

1. What effect will various MR&R actions have on:
   a. Deterioration Rates? ☐
   b. Service Lives? ☐
   c. Lifecycle Costs? ☐
   d. Budget Constraints? ☐
   e. All of the Above, Considering the Entire Asset Network? ☐

Programming

1. Which combination of actions will minimize the lifecycle costs of service provision? ☐

Feedback (Integration)

1. What have we learned from this process? ☐
2. What data reporting mechanisms are needed to ensure an efficient flow of information? ☐
3. Where could lifecycle phase integration bring about service improvements? ☐

Influence (Capital Budgeting)

1. How can capital budgets be improved from this process? ☐
2. What changes in project delivery would result in enhanced network performance? ☐

To calculate the score, add one point for each series of questions that could be answered.

Score Evaluation:

Score:

0, 1, or 2: Get serious about infrastructure management.
3: Good start, but many tasks lie ahead.
4 or 5: Good work, now use all this data and analysis.
6 or 7: Now improve your organizational capabilities.
8: Perfect! Keep up the good work.

Infrastructure Management QuickTest – Solutions

If your agency cannot answer a particular question, keeping you from effectively managing your infrastructure, consider these generic solutions.

Data – Network

1. Establish your inventory through a complete system-wide assessment of your capital assets. Identify key components of each type of asset, and the relationships between each asset. Identify all possible condition/performance states. Use computer technology (i.e. databases) to store all inventory and subsequent data. **Integrate all asset data into one inventory.**
2. Locate all assets using a coordinated system-wide referencing system that takes into account all asset types.

Data – Industry

1. Determine the expected design lifespans of all components of all assets. Identify all potential maintenance actions for all components for all condition/performance states. Allow flexibility for new technologies.
2. Tap into industry and in-house technical knowledge to determine the expected outcomes (costs and benefits) of each maintenance action on each component for each condition/performance state.
3. Again, tap into industry and in-house technical knowledge to determine expected outcomes (condition/performance state improvements) of each maintenance action on each component for each condition/performance state.

Needs – Current

1. Implement aggressive inspection program to identify condition/performance states of all assets. Repeat regularly and as needed.
2. Implement aggressive inspection program to identify condition/performance states of all assets. Repeat regularly and as needed.

Needs – Future

1. Determine modeling approach to predict remaining service life based on current and historical condition/performance states.
2. Model deterioration based on both condition/performance states and predicted maintenance policies and budgets.

Alternatives

1. (all) Simulate alternative effects of different policy choices and budget allocations on maintenance actions. Use these results to determine the effects of each maintenance action on (a) deterioration rates, (b) service lives, (c) lifecycle costs, (d) budget constraints, and (e) each of these over the entire network of assets.

Programming

1. Optimize results of alternatives analysis with respect to lifecycle costs. Schedule and budget for necessary maintenance actions.

Feedback (Integration)

1. Establish communication between various project participants to allow for feedback and discussion of potential future options.
2. Ensure that all required information is being collected by and disseminated to the proper project participants.
3. Discuss changes in project delivery with all project participants to understand how integration could help.

Influence (Capital Budgeting)

1. Identify the implications of repair vs. replace decisions and work to ensure that the most economical choices are being made.
2. Analyze the choices being made with respect to project delivery method to determine if the most economical choices are being made.

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