An Examination of Methods for Condition Rating of Sewer Pipelines

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ABSTRACT

The aging and deteriorating infrastructure in the United States is becoming an issue of utmost importance for engineers tasked with its maintenance. In addition to this assignment, engineers will soon also have to assist their agencies in meeting the new financial statement requirements set forth by the Government Accounting Standards Board (GASB) Statement 34. Engineers can both effectively maintain the infrastructure assets and fulfill the requirements of GASB 34 by implementing an asset management system. In this study, the requirements of GASB 34 and the aspects that make up an asset management system are discussed, as well as how they relate to sewer pipeline systems.

Pipelines are one of the more difficult infrastructure assets to maintain. This is due to the fact that they are primarily located below ground and not as easy to inspect as pavements and bridges. This has caused difficulty for engineers to cost effectively maintain their sewer systems. Using an asset management system that utilizes the “Modified Vani Kathula Condition Coding System Incorporated with a Condition Rating System” for rating the condition of sewer pipes, engineers can standardize the condition rating of their sewer systems. The condition ratings that are obtained through this method can then be analyzed using the Markovian Method or the Herz Survival Function to determine the remaining useful life of the pipeline. It is recommended that engineers use all components of an asset management system for sewer systems so they can more accurately predict the remaining life of the sewer pipeline system and thus more economically maintain this vital asset.

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CHAPTER ONE

INTRODUCTION

1.1 Background

The vast amount of aging and simultaneously deteriorating infrastructure in the United States has highlighted the need for improved engineering management tools. The 2001 American Society of Civil Engineers report card for America's infrastructure gives an overall grade of a D+ to the nation's infrastructure [1]. There is a strong need for new and improved management tools to help today's civil engineers develop new ideas and methodologies for replacement of the infrastructure.

Along with the deteriorating state of America's infrastructure, the Governmental Accounting Standards Board, who regulates how governmental agencies do their accounting, issued Statement Number 34, which requires all agencies to account for their infrastructure assets. Governmental agencies will now be required to assign a monetary value to their infrastructure. Through the use of the GASB 34 modified approach, governmental agencies will be able to best use their funding, so as to maintain and improve the condition of their infrastructure. GASB 34 will become a driving force that encourages agencies to become more accountable for their assets.

An area of particular concern for our nation's infrastructure is its pipeline systems. Much attention has already been given to the condition of our roads and bridges. On a daily basis, bridges and roadways are in full view of each and every one of us, so it is no surprise that the condition of these structures is assessed on a regular basis. Pipeline conditions have been overlooked for decades because of the "out–of-sight/out of mind" principle. Pipelines are typically underground infrastructure facilities whose condition is invisible to its owners, users, and the public at large. To date, little emphasis has been placed on documenting pipeline condition and determining how it changes with respect to time.

To better value and maintain infrastructure, engineers need to be able to predict its future performance. The importance of condition rating and deterioration modeling in any infrastructure management system is paramount. To predict infrastructure future performance, one must optimize the efficiency of maintenance, rehabilitation, and replacement whilst analyzing condition rating and modeling deterioration rates.

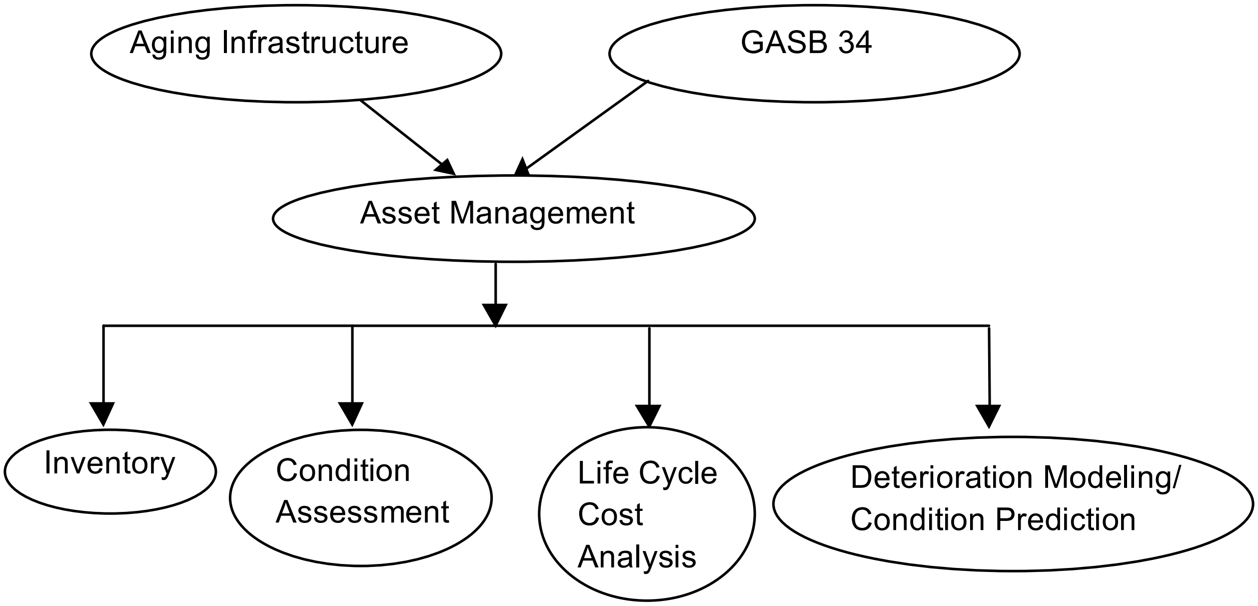
1.2 Objectives

The goal of this study is to provide infrastructure management professionals with a working knowledge of asset management methodologies. In particular, this study will review and analyze existing methodologies for condition rating and deterioration modeling for sewer systems.

1.3 Outline

To accomplish the objectives of this study, a literature search and synthesis on available information regarding GASB 34, asset management, life cycle cost analysis, condition rating of sanitary sewers and sanitary sewer deterioration will be performed. Simple example calculations of condition rating, and deterioration will be performed. Alternative condition rating and deterioration approaches will be compared and contrasted, and available computer software will be evaluated.

Figure 1.1 How it's all related



Chapter one has introduced the reader to the concept of infrastructure management and what it entails.

Chapter two will summarize and discuss the impending requirements of GASB 34 that all governmental agencies will have to follow.

Chapter three will discuss asset management, what it is and what is needed for its implementation.

Chapter four will discuss the value of using life cycle cost analysis to the infrastructure engineer.

Chapter five will discus how condition rating systems are developed for infrastructure assets.

Chapter Six will discuss methods for evaluating the condition of sanitary sewer pipelines; in particular vitrified clay pipelines.

Chapter Seven will explore methods for modeling and predicting deterioration and thus the future performance of infrastructure assets. In particular the modeling and predicting of sanitary sewer pipelines will be looked at.

This report will conclude with a summary of findings and recommendations.

CHAPTER TWO

GASB 34

2.1 Overview

The Government Accounting Standards Board (GASB) specifies the requirements that state and local governments must use when preparing financial statements. GASB is a private, non-profit, and relatively obscure organization that prior to 1999 was only a known entity within the accounting community. GASB is responsible for establishing and improving the accounting and financial reporting standards for more than 84,000 governmental units in the United States [2].

Statement 34 of the Governmental Accounting Standards Board (GASB 34), adopted in June of 1999 establishes new financial reporting standards for state and local governments throughout the United States. The main objective of GASB 34 is increased governmental accountability. GASB 34 requires that state and local governments now include capital assets, including infrastructure on their annual balance sheets and income statements. For the first time in history, citizens will now be privy to information regarding what it costs to design, build, operate, and maintain public infrastructure. In essence, the new requirements of GASB 34 are intended to make government annual reports more comprehensive and easier to understand and use.

It is important to note that GASB has no enforcement authority. Hence, the GASB 34 requirements have no muscle behind them. If they are so inclined, State and local governments can choose to ignore the requirements of GASB 34. However, those agencies that choose to ignore GASB 34 will have annual reports that do not meet industry accepted accounting practices. Any agency that uses bonds to fund their capital improvement projects will most likely have to conform to GASB 34 or risk receiving an unsatisfactory bond rating. Hence, it is anticipated that the majority of governmental agencies will conform to the GASB 34 requirements. The discussion below is a synthesis of material taken from the following references: [2] – [13].

2.2 Definition of a Capital Asset

Capital assets are government owned items, used in operations that have a useful life of greater than one year. Examples of capital asset include the following:

- Land, easements, and improvements to land.
- Buildings and building improvements.
- Vehicles, machinery, and miscellaneous equipment.
- Works of art and historical treasures.
- Infrastructure.

2.3 Definition of an Infrastructure Asset

An infrastructure asset is a long-term capital asset, normally stationary in nature that lasts longer than most capital assets. Examples of infrastructure assets include the following:

- Roads, bridges, and tunnels.
- Drainage, water, and sewer systems.
- Dams.
- Lighting systems.
- Buildings that are part of a network of infrastructure assets, e.g. road maintenance shops and garages, highway rest area facilities, water pumping buildings associated with water systems, waste treatment buildings associated with wastewater treatment.

2.4 Reporting Capital Assets

GASB 34 requires that capital assets be reported at historical cost. The cost of a capital asset includes the following:

1. The cost of the asset.
2. Any capitalized interest associated with the asset.
3. Any costs associated with the acquisition of the asset, such as freight, transportation, site preparation, and professional fees.

2.5 Implementation of GASB 34

GASB 34 affords state and local governments two different alternatives for implementing the new requirement to report infrastructure assets on financial statements; namely, the depreciation method or the modified approach.

2.5.1 The Asset Depreciation Method

The depreciation method is what the business world has used for years. It is the process of allocating the cost of tangible property over a period of time, rather than deducting the cost as an expense in the year of acquisition [3].

In the depreciation method, the cost of an infrastructure asset less its salvage value is divided by its assumed useful life to arrive at a yearly cost. The yearly cost is then deducted until the accumulated depreciated cost equals the original cost less the salvage value.

The depreciation method involves the following:

1. Assigning a value to each network of infrastructure assets, subsystem of infrastructure assets, or individual assets.
2. Depreciating the infrastructure asset, on a yearly basis over its useful life.

2.5.2 The Modified Approach

The modified approach was added as an alternative to the depreciation method. The depreciation method does not take into consideration maintenance costs and the effect of maintenance on the assets useful life.

The Governmental Accounting Standards Board added the modified approach to statement 34 as a result of a proposal submitted by the American Association of State Highway and Transportation Officials (AASHTO) [4]. The AASHTO proposal was a result of the input of many state and local governments, which have referred to the depreciation method as a number crunching exercise that is unlikely to produce useful infrastructure management data. In the modified approach, infrastructure that is managed through the use of an asset management system is exempt from the requirement to report depreciation. It is the belief of AASHTO that assets, which are maintained, should not have to be depreciated because they are being preserved at a predetermined condition level.

The modified approach may be used provided the agency meets the following three requirements:

1. It has a current inventory of the infrastructure assets.
2. It documents that the infrastructure assets function at or above a condition level established by the agency.
3. It annually estimates the cost required to maintain the infrastructure assets at a minimum condition level.

The reader should note that a complete condition assessment is not required for every item within an infrastructure network or subsystem. In fact, a condition assessment may be performed using statistical samples that are representative of the infrastructure asset.

2.5.3 Compliance Dates

Reporting requirements are being implemented in three phases. Agencies are broken down into three categories for complying with the reporting requirements of GASB 34 based on their annual revenues. There are two different reporting requirements that each agency needs to follow. The first requirement is to report all new infrastructure assets. The second requirement is to retroactively report existing infrastructure assets that were acquired, reconstructed, or improved after June 30, 1980.

2.5.3.1 New Infrastructure Reporting Requirements

- Phase 1: started with the fiscal period starting after June 15, 2001 for agencies with greater than $100 million in annual revenues.
- Phase 2: starts with the fiscal period starting after June 15, 2002 for agencies with greater than $10 million and less than $100 million in annual revenue.
- Phase 3: starts with the fiscal period starting after June 15, 2003 for agencies with less than $10 million in annual revenues.

2.5.3.2 Retroactive Reporting Requirements

- Phase 1: starts with the fiscal period starting after June 15, 2005 for agencies with greater than $100 million in annual revenues.
- Phase 2: starts with the fiscal period starting after June 15, 2006 for agencies with greater than $10 million and less than $100 million in annual revenue.
- Phase 3 participants are encouraged, but not required to start with fiscal period starting after June 15, 2007 for agencies with less than $10 million in annual revenue.

2.6 The Depreciation Method vs. the Modified Approach

The single greatest benefit of instituting the modified approach is that the value of an agency's infrastructure assets will reflect the importance and worth of maintenance activities. The modified approach requires agencies to routinely assess the condition of their existing infrastructure. More information regarding infrastructure condition will no doubt assist the asset manger in resource allocations and project level decisions.

The depreciation method will require asset managers to perform nearly the same amount of work as the modified approach. In the depreciation method, one must develop an inventory of all infrastructure assets and assign a value to each one. The depreciation method does not take into account the value added or maintained by the asset based on maintenance activities. The end result of the depreciation method is of little worth to the asset manager because it sheds no light on the asset's current condition.

2.7 American Public Works Association Policy Statement on GASB 34

The American Public Works Association (APWA) endorses and urges local and state to adopt the modified approach. The APWA believes that the depreciation method is not the way to represent the value of infrastructure. The APWA has concluded the following with respect to the depreciation method [5]:

- It often presents misleading representation of actual value and ownership costs of a community's infrastructure.
- It reduces the value of financial statements as a management tool.
- It does not show actual deterioration, repair and upgrading that result from day to day operation of public works departments.

2.8 Recommendation for Using the GASB 34 Modified Approach

In general, in the public sector there exists a lack of knowledge regarding the condition of the existing infrastructure. Today's engineers and asset managers are in great need of tools to assist them in determining how and when to allocate scarce resources.

Civil engineers responsible for designing, supervising the construction, estimating the cost of, and maintaining the infrastructure, should use the modified approach. The modified approach is the most valuable management tool. The depreciation method is merely a tool for accounting professionals and is of little value to engineers.

2.9 Steps Required for Implementation of the GASB 34 Modified Approach

The modified reporting method will require governments to do the following:

1. Develop an up to date inventory of all infrastructure assets.
2. Perform condition assessments on infrastructure assets at the network or subsystem level. Summarize the condition levels in a replicable manner using a measurement scale.
3. Each year estimate the annual amount required to maintain the infrastructure at or above the minimum acceptable condition level.

4. Complete a condition assessment of each infrastructure system or subsystem at least every three years.
5. Document that the three most recent condition assessments provide reasonable assurance that infrastructure is being preserved at the established condition level.

2.10 GASB 34 Areas of Concern

The intentions of GASB 34 are good. In fact, it is unfathomable that until the advent of GASB 34 governmental agencies did not include the value of their capital assets on their annual reports. Certainly, no private sector entity would dream of preparing a statement of net worth without valuing its capital assets [6]. However, there do exist some inherent problems with GASB 34, which will be discussed in the ensuing subsections.

2.10.1 Financial Reporting Inconsistencies

The financial data that is obtained through GASB 34 reporting will be used by bonding agencies to determine the bond rating of governmental agencies. Agencies that choose the depreciation method will have assets that are still functioning and useable but have no book value. Agencies that opt for the modified approach will have a book value for all of their assets. Thus, one could speculate that by choosing the modified approach over the depreciation method, one agency might falsely appear to have a better financial standing.

2.10.2 Condition Reporting Inconsistencies

Currently, there exists no standard condition rating system for any infrastructure asset. Similarly, no standard minimum acceptable condition levels at which the infrastructure must be maintained at or above have been developed. Hence, the manner in which one agency chooses to asses its infrastructure condition rating or the level to which the agency maintains its infrastructure could give the appearance that one municipality or state is better off financially than another is when in fact they are not.

2.10.3 Frequency of Condition Level Assessment

The current requirements of the modified approach obligate agencies to perform condition level assessments every three years. With these requirements, there is the perception that agencies will be required to devote valuable resources to perform condition ratings every three years. Although condition ratings can be done by statistical sampling of a network or system, there will still be time and money involved in doing this for assets that historically deteriorate slowly over time. It does not make much sense to inspect a new sewer system every three years when the systems have design lives of 80 to 100 years.

2.10.4 Future Performance

GASB 34 does not take into account the systems future performance. The key to best utilizing the scarce available resources for maintaining the infrastructure is to know when to apply the funds. The depreciation method of GASB 34 does not care how these funds are used. The modified approach simply requires that the agency is spending enough funds to maintain an arbitrary condition level.

2.11 Summary GASB 34

GASB 34 will require much time and effort to be established within any agency. GASB 34 brings different stakeholders to the same table. They include engineers, maintenance, operations, finance, and management. GASB has no enforcement authority or resources. Failure to comply can result in lack of public accountability, undermining of public confidence, and the lowering of an agency's bond rating.

A standardized method of rating the condition of all infrastructure assets needs to be developed. By implementing a standardized method for rating the condition of all aspects of infrastructure, a better model for determining their deterioration can be developed. GASB should be amended to include a method of predicting the future performance of the infrastructure.

If an agency chooses the modified approach of GASB 34, they must be able to provide documentary evidence that they are meeting the condition assessment requirements of GASB 34. One way to document that condition assessments are being performed and the asset is functioning at or above the minimal acceptable level is to implement an asset management system.

In the next chapter, an in-depth look at asset management will be presented.

CHAPTER THREE:

ASSET MANAGEMENT

3.1 Objectives

In the preceding chapter, GASB 34, the new accounting standard for governmental agencies, was discussed. Agencies that choose to implement the GASB 34 modified approach should proceed one step further and develop an asset management system. This chapter will focus on an in-depth look at asset management. Asset management will be defined. The history and future of asset management will also be discussed. The discussion below is a synthesis of material taken from the following references: [4], [6], [11], [14], [15], and [16] – [23].

3.2 Definition of Asset Management

Asset management is a systematic process of operating, maintaining, and upgrading assets in a cost-effective manner. It is a marriage of sound engineering practice and business acumen. It enables today's engineers to plan for both the short and long term in an organized, logical and methodical manner.

3.3 Background of Asset Management

Engineers and those individuals tasked with infrastructure management often must determine how to disperse scarce funding without having an overall picture of the infrastructure they manage. Infrastructure decisions are routinely made with incomplete data in the presence of competing and equally worthy needs. In light of vying interests, engineers must often prioritize projects in advance of five or more years before their actual construction date.

For years, businesses have practiced asset management. Businesses have found asset management to be a tool for staying competitive because it assists them in efficiently, effectively, and comprehensively managing their assets. As more and more citizens begin to demand that their governmental agencies become more fiscally responsible, asset management has begun to make its way into the public sector.

3.4 History and Methodologies of Infrastructure Asset Management

Today's engineers employ numerous different approaches to managing the existing infrastructure. The traditional infrastructure asset management strategies are as follow [23]:

- Operative
- Inspection
- Preventive
- Predictive

3.4.1 Operative Based Asset Management

The most basic approach to infrastructure asset management is the Operative system. In this method, operation and maintenance records are kept. Failures are documented for future reference or analysis. In essence, this method employs the "fail-fix" mentality in which the infrastructure failure is either rehabilitated or replaced. This method is not a good engineering practice because it can result in catastrophic failures, which can endanger human life and/or result in significant property damage. This method is not a financially responsible choice. It is always more expensive to fix something after it has failed than to repair it prior to its failure. If a sewer system can be repaired prior to failure, it will prevent a plethora of costly problems, such as the backup of sewage into basements.

3.4.2 Inspection Based Asset Management

The Inspection strategy of asset management is one step more sophisticated than the Operative system. This method involves periodic inspection and rehabilitation or replacement as determined by the inspection results. This method of asset management is the one most commonly employed at this time by local governments for asset management. This method of asset management is commonly referred to as "worst-first", where the assets in the worst condition are fixed first. An example of this method would be to inspect a community's sewers throughout the town and then repair those that are in the worst condition first. This method does not utilize available funding to the fullest extent possible.

3.4.3 Preventative Based Asset Management

The next rung of asset management is the Preventive strategy. Assets are rehabilitated and/or maintained at fixed intervals in this practice. This strategy primarily relies on the organization's past operating history and experience. This method is commonly referred to as a rule of thumb approach to asset management. This is the asset management system typically employed by private utility owners. Agencies that choose the depreciation approach to GASB 34 will most likely institute this type of asset management practice. This type of asset management is similar to changing the oil in your car every 3,000 miles.

3.4.4 Predictive Based Asset Management

In contrast to the traditional strategies, Predictive asset management is based on optimizing infrastructure performance and reliability at the lowest possible cost. This is the most desirable approach to asset management because it encourages better prediction of failures, planning for repairs and or replacements, and resource allocation.

3.5 Components of a Total Infrastructure Asset Management System

There are a number of elements that make up an asset management system. An effective asset management system should include these five items:

- An inventory of infrastructure assets.
- A method for assessing the condition of the assets.
- Ability to predict the future condition of the assets.
- A resources allocation model.
- The ability to assign a monetary value to infrastructure assets.

3.5.1 Infrastructure Inventory

The foundation of an infrastructure asset management system is the inventory. Accurate data is the most important aspect of the asset management system. The infrastructure inventory should be thorough and continually updated. Some of the items that should be included in the infrastructure inventory are:

- Original construction costs.

- Physical location of the asset.
- Design characteristics of the asset.
- Construction history including maintenance activities.
- A description of the use of the asset, i.e. traffic volumes, sewage volume, etc.
- Conditions encountered during construction, i.e., soil types, weather, etc.
- Material specifications of the asset.

The most effective way to maintain and easily update and access inventory is to have it contained within a geographical information system (GIS).

3.5.2 Infrastructure Condition Assessment

A method must be in place to determine what condition the asset is in. All assets need to be inspected and rated on a predefined scale that is established by the agency. The asset's current condition level is used to help determine what type of maintenance activity should be applied to the asset and when it should occur. The establishment of a condition rating format will be looked at further in chapter five.

3.5.3 Prediction of the Infrastructure's Future Condition

Once the inventory has been taken and the current condition of the asset has been determined, the future condition of the asset should be predicted. By predicting the future performance of the asset, an engineer will be better able to better determine in what manner and when to maintain the asset.

If the future condition and performance of the assets can not be reasonably predicted, the agency has no way of determining how much money will be needed for future repairs and maintenance. Future condition predication is one, if not the most, difficult part of an asset management system.

To date there has been little research in the area of infrastructure future performance prediction in the United States. Thus far, pavements and bridges have had the most work done on predicting their future performance. Currently, only approximations and expert opinions are used to ascertain the expected life of pipelines. This is not accurate because many factors can and do effect the deterioration and thus the useful life of piping systems. The performance prediction of sewer pipelines will be more thoroughly discussed in chapter seven.

3.5.4 Infrastructure Resource Allocation

After the future performance of the asset has been predicted, an analysis of the asset system can be performed to determine how much funding is needed to keep the entire system at or above an established minimum standard condition. Many of the software programs that are available for doing asset management aid the engineer in doing this procedure. This analysis can be done in a number of ways. One way is to enter in how much funding is available for a number of years. The analysis program then selects what maintenance and repair items should be performed on what segments of the asset to give the best overall system condition. One can also determine how much funding is needed every year to maintain a certain condition rating.

3.5.5 Monetary Value of the Infrastructure

Once the future condition of the asset has been determined based on the selected maintenance and rehabilitation, the total value of the asset system can be determined. Then the engineer can see if the assets that they are responsible for are gaining, losing or maintaining their value. This is also how the need for future budgets is determined.

3.6 Benefits of an Asset Management System

There are many benefits of an asset management system for both the infrastructure engineer and the citizens who use the asset.

3.6.1 Ease of Infrastructure Reporting

An asset management system will fulfill the new yearly infrastructure reporting requirements set forth in GASB 34. The ability to predict the infrastructure's future condition will allow a benefit cost analysis to be done to determine how the available funds should be used to best improve and prolong the life of the entire infrastructure asset system.

3.6.2 Streamlined Decision Making

An asset management system will streamline the decision making process with respect to infrastructure maintenance and rehabilitation. The manager will benefit by having easy access to improved information, which will save the manager a great deal of time. It will also take the guesswork away from the manager and provide them with documentation of their decision making process illustrating how the chosen option affected the condition rating of the given asset.

The utilization of an infrastructure asset management system will aid the decision-makers in facilitating economic assessments of trade-offs for different types of maintenance. It will provide improved information with respect to return on investment and understanding the value of investments. It will reduce both short and long-term costs by helping to determine how best to allocate the available funding to get the “most bang for their buck”.

3.6.3 Taxpayer Benefits

The engineers of the infrastructure asset will be able to best determine what maintenance to perform and when to do it to give the longest life to the asset. This will reduce the number of times that maintenance will need to be performed on the asset which will reduce the amount of time that the user will need to be inconvenienced by such things as detours, lack of service, and other general inconveniences.

When the asset managers are able to determine the best method of maintenance for an asset, they can also improve its overall performance. This improved performance benefits the users by giving them such things as improved ride comfort on their roads and improved safety of they sewer and water systems.

When the assets are better cared for and the funding of them is allocated such that its life is extended to its fullest extent, the overall cost of maintaining the asset systems is reduced. This reduction in the cost to maintain the assets can then be passed on to the taxpayers that finance their existence.

3.7 How to Make an Asset Management System Succeed

Merely devising and implementing an asset management system does not guarantee that it will succeed. It takes hard work by the managers of the system, the people who will use and maintain the information in the system, and the political figures of the agency.

3.7.1 Intertwine the Asset Management System and the Agency's Mission

One way that an asset management system manager can aid in the success of the system is to tie the functions of the system to the vision and mission of the organization. When the asset management system is an integral part of the organization's existence, it will be given the time and care that it needs to succeed. It is equally important for the managers to acquire, train, and retain highly skilled personnel to manage and use the system. As earlier stated, the most important component of the asset management system is having accurate and timely data in the inventory. It is crucial to have skilled and competent personal to do the work of maintaining and updating the necessary data.

3.7.2 Ensure the Asset Management System is Customer Orientated

The asset management system is most effective and efficient when it is focused on the customer. Focusing on the customer's needs is how businesses succeed. It is this same mentality that the users of an asset management system must have for it to be accepted and successful.

3.7.3 Garner Political Support

When all is said and done the most important key for the success of an asset management system is the backing by the elected officials of the agency. Political figures come and go. Each new political regime must be sold on the importance and benefits of asset management. Politicians must fully support the concepts of asset management and stand up to all questions of its need and usefulness.

3.8 Why an Asset Management System Might Fail

There are many reasons why an asset management system might fail. The sources of failure range from the users of the systems to the political nature of the agency. There are inherent potential failure mechanisms within asset management itself.

3.8.1 Challenge of Predicting Asset Life

There is the challenge of predicting the life of the assets. There has been substantial research in the prediction of future performance and life expectancy of pavements and bridges. However there has been little work on this for pipeline systems. It is also not adequately known how different maintenance procedures affect the life of pipelines.

3.8.2 User Resistance

The users of the system may resist such a system. Some engineers may feel as though a machine is replacing them. Many people who have been maintaining assets for a long time may say "I've always done it this way and it has worked, why change now?" It may be difficult to enlighten these people to the benefits that asset management can provide.

3.8.3 Start-up Difficulties

Asset management systems are not easy to set up and start. They cost money to get started and to maintain. Although this initial investment will be paid back many times over when an asset management system is properly and fully used, some politicians may not see that. Politicians are generally looking for results right now since their terms are relatively short and they need results to be reelected. Because of political pressure, managers may promise implementation and results before they are realistically practical. This can cause the system to be abandoned before it ever gets fully started or is given a fair chance.

3.9 Summary

By properly utilizing asset management systems, engineers and decision-makers will be able to make better investment and resource allocation decisions.

The most time consuming portion of an asset management system and that of the modified approach to GASB 34 is the building and maintaining of the infrastructure inventory along with the required inspections and condition ratings.

The life cycle cost analysis of choosing the most appropriate maintenance activity resulting in the greatest benefit will be discussed in the next chapter.

CHAPTER FOUR

LIFE CYCLE COST ANALYSIS

4.1 Objectives

In the preceding chapter, asset management was discussed. One of the essential components of an asset management system is life cycle cost analysis. In this chapter life cycle cost will be discussed. The discussion below is a synthesis of material taken from the following references: [24] – [31].

4.2 Definition of Life Cycle Cost Analysis

A life cycle cost analysis (LCCA) is a method of calculating the cost of a system over its entire life span. The analysis of a typical system should include such costs as system planning and concept design, preliminary design, construction and inspection, maintenance, and rehabilitation or replacement.

Life cycle cost analysis is an engineering economic analysis tool that allows engineers to quantify the differential costs of alternative investment options for a given project. It is the sum of the initial, operating, and maintenance costs.

4.3 Background of Life Cycle Cost Analysis

In January 1994, President Bill Clinton signed Presidential Executive Order 12893 that states:

> “A well-functioning infrastructure is vital to sustained economic growth, to the quality of life in our communities, and to the protection of our environment and natural resources. Our Nation will achieve the greatest benefits from its infrastructure facilities if it invests wisely and continually improves the quality and performance of its infrastructure programs.” [26]

The first step recommended in the Order is:

> "A systematic analysis of expected benefits and costs. Benefits and costs should be measured and appropriately discounted over the full life cycle of each project. Such analysis will enable informed tradeoffs among capital outlays, operating and maintenance costs, and non-monetary cost borne by the public." [26]

With the growing age of our nation's infrastructure, an increasing amount needs to be rehabilitated or replaced. At the same time, our country is continuing to grow and expand outward from our cities. These two phenomena of the infrastructure are competing for the limited funding that is available. The use of life cycle cost analysis aids engineers in selecting the most cost effective methods of maintenance, rehabilitation, replacement and reconstruction design.

4.4 Purpose of Life Cycle Cost Analysis

The purpose of life cycle cost analysis is to identify the lowest long-term cost of a project over its entire life span. By doing so, the agency can save money in the future and can show the taxpayer that they are acting in a financially responsible manner.

4.5 American Society of Civil Engineers Policy on Life Cycle Cost Analysis

The American Society of Civil Engineers has issued a policy that encourages the use of life cycle cost analysis in the design phase to evaluate the total cost of projects. They issued this policy because they believe that it will lead to quality engineering on all projects. They believe that it is good practice and should be followed by state and local agencies in making program and project investment decisions. Their policy states that all costs involved throughout a project's life should be included in the analysis. These costs include the following [31]:

- Initial construction
- Operation and Maintenance.
- Environmental.
- Safety.
- Any other reasonably anticipated cost incurred during the life of the project.

4.6 Federal Highway Administration Policy on Life Cycle Cost Analysis

The Federal Highway Administration (FHWA) believes that the life cycle cost analysis should be used on all projects. They have even developed software to aid engineers with this task for pavement design. The FHWA policy states the following [26]:

- It is important to use life cycle cost analysis to maximize the return from investments.
- Continued use of LCCA will help reduce costs.
- LCCA should be considered in all phases of construction, maintenance and operations.
- The analysis period of a LCCA should be long enough to capture long-term differences in discounted life-cycle costs among competing alternatives and rehabilitation strategies.
- All agency and user costs should be included.
- Future costs should be discounted to their Net Present Value.
- Discount rate should be consulted with the Office of Management and Budget Circular A-94.

4.7 Procedure

To successfully perform a life cycle cost analysis the following steps should be followed:

1. Define the analysis period for the project.
2. Define the alternatives.
3. Identify future activities and their timing throughout the project’s life.
4. Construct a schedule of activities for each alternative.
5. Estimate both agency and user costs.
6. Add the estimated costs to the activity schedule.
7. Discount future costs to present dollar values.
8. Determine the life cycle costs.
9. Analyze the results.
10. Reevaluate the strategies.

4.7.1 Analysis Period

The analysis period should be long enough to cover the full life expectancy of the investment including at least one rehabilitation activity. This is necessary to reflect the cost differences between the alternatives. The time period covered should be that which would cover the project until it would have to be reconstructed if it were initially constructed to an optimum design.

4.7.2 Define Alternatives

All possible options should be listed and considered no matter how expensive their initial costs are believed to be. It must be kept in mind that although an option may have a higher initial cost, its cost over the entire life of the project may be lower than other options with lower initial costs. This can be the case many times in pavement design when concrete is ruled out prematurely due to its high initial cost.

4.7.3 Identify Future Activities

Once all the alternatives have been defined, the future activities that will be necessary to extend the life of each alternative to a point where they are all equal should be identified. Examples of this are maintenance activities such as overlays and chip seals for pavements and sewer cleaning and root cutting in sanitary and storm sewers.

4.7.4 Construct a Schedule of Activities

A schedule of activities for each alternative must be constructed. This schedule could be similar to a timeline, which shows when each maintenance activity would take place in the life of the alternative.

4.7.5 Estimated Costs

Costs must include all appropriate agency or user costs that are anticipated during the analysis period used for the alternatives.

Examples of agency costs include:

- Traffic control costs during maintenance and rehabilitation.
- Costs of special construction procedures required to maintain traffic.
- Agency operating cost for the system, e.g. lighting.

Examples of user costs include:

- Increased vehicle operating costs.
- Accident costs.
- Delay costs.
- Cost due to deteriorated ride surface and/or circuitous routings.

4.7.6 Add Estimated Costs to the Activity Schedule

Next, the estimated costs must be added to the activity schedule. By doing this the engineer can see what the future costs will be for each alternative and when they will occur.

4.7.7 Discount Future Costs to Present Dollar Values

Future costs must be estimated in constant dollars and then discounted to present dollar values. Constant dollars have the same purchasing power over time. Constant dollars assume that the time value of money offsets any inflation that occurs. Future costs are discounted using an appropriate discount rate to compare costs incurred at different points in time. The discount rate used should reflect historic trends over long periods of time. The discount rate selected can significantly influence the results. It is important to be consistent with the monetary values that are being used so the results are valid. It is best to use constant dollars and real discount rates to eliminate any possible confusion. Real discount rates reflect the true time value of money without inflation.

The Office of Management and Budget (OMB) Circular A-94 “Guidelines and Discount Rates for Benefit-Cost Analysis’s of Federal Programs” gives guidance for selecting discount rates. When determining future costs, if an alternative has some useful life or salvage value left at the end of the analysis period, this value should be based on its remaining life as a prorated share of the last rehab cost. After all future costs have been discounted to the net present value the total life cycle cost for each alternative can be found. The engineer should then analyze these results and reevaluate the alternatives that were originally presented.

4.8 Keys to Success

The key to success in the use of life cycle cost analysis is to do it early in the project life. If LCCA is done too far into the life of a project it loses its impact to make a cost-effective decision on which alternative is best.

It is important to spend sufficient time to ensure the level of detail of the analysis is appropriate for the project. The time and level of detail should be representative of the level of investment of the project. If the project is only tens of thousands of dollars, the LCCA should be relatively short and simple. If the project is tens of millions of dollars, the LCCA should be much more detailed and have much more time spent on its evaluation.

4.9 Uncertainty and Risk Analysis

It is important to be aware of the uncertainty surrounding the variables used as inputs into the analysis and the risks this uncertainty creates in the results. This is especially true with the choice of discount rate. Risk analysis is a technique that exposes areas of uncertainty and allows the decision-maker to weigh the probability of any particular outcome occurring. It combines probability descriptions of uncertain variables and computer simulation to characterize risk associated with the outcome. This gives the decision-maker the opportunity to take mitigation action to decrease exposure to the risk involved.

The use of risk analysis is most important when two or more alternatives are close in cost. When this occurs, performing a risk analysis will further assist the engineer in selecting the most economical, long term, choice.

4.10 Summary

Life cycle costing analysis should be used for all decisions related to infrastructure design, construction, operation, maintenance, and rehabilitation alternatives. The engineer and other decision-makers must decide what is the overall best design option based on the project's net present value. It is important to be consistent when performing a life cycle cost analysis.

In the next chapter, the importance of establishing a condition rating system will be discussed.

CHAPTER FIVE:

ASSET CONDITION RATINGS

5.1 Objectives

Thus far, this paper has explored the impending changes that agencies will have to make in the way they account for their infrastructure assets. It is believed that this change will result in more agencies using asset management systems. The previous chapters have defined asset management and have looked at life cycle cost analysis as being one of the components of an asset management system. In this chapter, another essential element of asset management will be examined. Condition rating systems for infrastructure assets will be discussed. The discussion below is a synthesis of material taken from the following references: [15], [32].

5.2 Definition of Condition Rating

Condition rating is an evaluation of the infrastructure's current physical state versus its newly constructed state. Condition ratings should be descriptive and based on observed deficiencies.

5.3 Background of Condition Rating

Aging is a part of life. From the minute something is born or created, it begins to age. Nothing lasts forever. The only way to predict the future performance of the infrastructure is to first assess its condition. The determination of condition ratings assists with the establishment of priorities for rehabilitation and or replacement projects.

Condition ratings are usually numerically based. These scales can either have the highest or lowest value in the scale indicating that the condition of the particular infrastructure asset is in new condition. The either the lowest or highest value in the scale denotes that the item has failed and is not working.

5.4 Purpose of Condition Rating

The purpose of conducting condition ratings on infrastructure assets is to determine their remaining useful life.

5.5 Condition Assessment Methodologies

The basic concept for assessing the condition of an infrastructure asset is to measure the type, severity and extent of deterioration that the asset is currently experiencing. A number of methods can be used to assess the condition of assets. They include [15]:

- Subjective ratings.
- Visual evaluation.
- Destructive testing.
- Direct measurement.
- Response type devices.

5.5.1 Subjective Ratings

Subjective ratings are based on a predefined scale. The rating scale is arbitrary. This rating method necessitates the use of trained inspection personnel. Subjective ratings are generally based on a scale of 0 to 5, with 0 being bad and 5 being good. Ratings are established on how the individual rater perceives the condition of the particular asset being examined.

One example of this type of rating is to simply drive down a road and rate the pavement condition based on ride comfort. Similarly, a rater could view a close circuit television videotape of a sewer pipe and assign a rating based on how they perceive the pipe condition, without determining or documenting any of the pipe defects.

5.5.1.1 Leniency Errors

Leniency is one of the three main problems that can occur in subjective condition rating when one rater is consistently too high and another is too low.

5.5.1.2 Halo Effect

Another potential problem of the subjective rating method is that the rater may have a preconceived idea of what the condition of a particular asset is in. The rater may then force the rating to the preconceived level, which they have already associated with the asset. For example, the halo effect may occur if the rater knows that others believe a particular road is in poor condition and should thus be replaced.

5.5.1.3 Central Tendency

The last area of concern for the subjective rating method is the central tendency. In central tendency errors, the rater does not want to assign any asset a high or low rating. The rater tends to rate everything as being in roughly the same condition, i.e. the “middle of the road” phenomena.

5.5.2 Visual Evaluation

In the visual evaluation method, the distresses observed by the rater during the inspection are recorded and documented for future reference. This method can be somewhat time consuming and thus costly. This method is somewhat similar to the subjective method, since the rater has to look at the asset and then record what they observe. The same problems that can occur with the subjective method may also occur with visual evaluation.

5.5.3 Destructive Testing

The destructive testing method has mainly been used in the evaluation of pavements and bridges. In this method, an actual piece of the infrastructure is taken and examined. The most common procedure of this method involves taking a core sample. Doing so could jeopardize the structural integrity of the pipe and cause a failure.

Destructive testing is of little use on determining pipe condition because an actual specimen needs to be taken. It would be difficult to cut a piece out of a pipe and test it to determine its condition.

In this method, the possibility exists that the sample is not representative of the entire pipeline being rated. The sample may have been taken at a location where the pipe is in good condition or bad condition.

5.5.4 Direct Measurement

The direct measurement method is the most labor intensive and thus most costly. In this method the rater measures and records the type, size, and location of all the distresses they observe. This recorded information is then used to determine the condition of the asset. This method has been most commonly used in the condition assessment of pavements. Direct measurement can be an extremely time consuming and expensive process.

5.5.5 Responsive Type Devices

Responsive type devices are the newest method for determining the condition of assets. This method inputs energy into a physical system and then measures the assets response. There are two types of responsive testing devices, ones that must be in contact with item being examined and those that do not. The contact devices include such things as electromagnetic, sonar, dynamic loading, and ultrasound.

Currently, the most common application of this method is for pavement condition ratings. The method used in pavement condition rating is the dynamic loading process, which consists of dropping a weight onto a pavement and measuring the deflection. The distance the pavement deflects is recorded and from that a condition rating is determined.

The non-contact devices include radar, thermal, and optical. These non-contact responsive devices may revolutionize the way the condition of pipe systems is determined. There is currently an Australian company that is marketing a product named PIRAT (Pipe Inspection Rapid Assessment) that utilizes both laser and sonar to determine the extent of deterioration in pipe systems [32]. These types of devices are still being perfected. The use of non-contact devices is cost prohibitive for most agencies.

5.6 Keys for Successful Condition Rating Systems

The following is a list of a few key components of condition rating systems that users must be aware of to assure their success.

- Condition rating system must cover all aspects of deterioration for the asset. If types of deterioration are not included the results will not be valid.
- To ensure consistency, condition rating must be replicable. It is important that someone else can use the condition rating system and obtain the same results.
- The system must be relevant to its users. There has to be a reason for doing the ratings, i.e. improved decision-making.

5.7 Potential Problems with Condition Rating Systems

The establishment of an infrastructure asset condition rating system can be a daunting task. Besides those potential problems discussed earlier in the chapter there are other numerous elements that can cause problems with condition rating. Much about the infrastructure assets is not easily known at the time of the condition rating. Uncertainties can cause variations in the condition ratings. These uncertainties include the following:

- Loads.
- Material properties.
- Weather.
- Soil conditions.
- Construction quality.

No two facilities are identical. Variations within facilities, between identical components, the environment, and use, can lead to non-uniform deterioration. Examples of this include a roadway experiencing a rapid increase in traffic volume or a new industry discharging wastewater into the sanitary sewer pipeline that contains different chemical properties.

5.8 Summary

This chapter has presented the different methodologies that can be used to determine the condition of an infrastructure asset. They range from the simple Subjective Method to the labor extensive Direct Measure Method to the technical use of Responsive Devices. The most important aspects of any condition rating system are consistency and repeatability.

In the next chapter, a condition rating system for sewer pipelines will be presented.

CHAPTER SIX

CONDITION RATINGS FOR SANITARY SEWER PIPELINES

6.1 Objectives

The previous chapter discussed methods that can be used to rate the condition of infrastructure assets. As with all the aspects of asset management for sewer systems, little has been done with regards to developing a condition rating system for sewer pipelines. This chapter will take a more specific look at assessing the condition of sewer systems. This specific look will include a suggested methodology for the rating of the condition of sewer pipelines. The discussion below is a synthesis of material taken from the following references: [33]-[37], [40], [41], [49], [51], [54], [55].

6.2 Deterioration of Sanitary Sewer Pipelines

Deterioration is the process by which the pipe structure itself decays to the point of failure. In the deterioration process, initial defects occur and over time progress to cause failure. Initial defects include cracking, leaking joints, material flaws, and poor workmanship practices such as improper pipe bedding, poor pipe handling practices and damage caused by third parties [33].

6.2.1 Definitions of Pipeline Defects [33] [34] [35]

Intact – A pipeline that is in the as-built or new condition. No defects are noticeable.

Crack – A partial break or fracture of the pipe material. The crack can run longitudinally or circumferentially.

Open Joint – When two abutting pipelines are not in full contact with one another, i.e., longitudinal displacement.

Displaced Joint – When the ends of two abutting pipelines are offset vertically.

Corrosion – When the cementious material, either pipe or pipe joining material, has been worn away.

Deformation – When the pipelines original cross sectional area has been altered.

Collapse – When the pipeline has completely failed. There is no longer any structural integrity remaining in the pipeline.

6.3 Exfiltration and Infiltration of Sanitary Sewer Pipelines

Sewer systems that are in poor condition with cracks and open joints experience exfiltration of sewage and infiltration of groundwater. These defects can eventually lead to the collapse and thus ultimate failure of the sewer [36].

6.3.1 Exfiltration

Exfiltration of sewage can cause the soils around the leaking pipe to become contaminated with waste. In sensitive areas, such as wetlands, lakes, or streams, the effects of exfiltration can be devastating to the surrounding Eco-system.

6.3.2 Infiltration

Infiltration of ground water into the sewer system causes large amounts of relatively clean ground water to be conveyed to sewage treatment plants for processing. The treating of clean ground water adds to the cost of operating the treatment plant. Infiltration in areas dependent on groundwater for recharge (wetlands, lakes, streams and drinking wells) may alter the associated Eco-system in an unfavorable manner. Infiltration will use up a portion of the sewer pipe and treatment plant's capacity. Lastly, Infiltration can cause portions of the system to back up and cause flooding or inadequate treatment at the plant.

6.3.3 Infiltration and Exfiltration Deterioration

Infiltration and exfiltration deterioration, aside from being environmental concerns, increase the rate of sewer pipe deterioration [33], [36]. As these processes occur, the soil that surrounds and helps to support the sewer pipe is eroded. This loss of side support provided by the soil causes the pipe to move outward, thereby causing pipe deformation and eventually leading to collapse.

6.3.4 Infiltration and Exfiltration Failures

Infiltration and exfiltration failures require immediate rehabilitative construction, once discovered. Immediate and unplanned system repairs are high in cost and may require shifting of available resources or the use of emergency funds to complete.

6.4 Condition Coding of Sanitary Sewer Pipelines

To date, there has been no standardized method of assessing the condition of sewer systems developed. Agencies that perform condition assessments of their sewer systems predominantly rely on Closed Circuit Television (CCTV) or man entry inspection in large diameter pipelines.

Currently, the most cost-effective method for rating the condition of sewer pipelines is the Visual Evaluation method. For man entry inspection, defect recording is carried out while the inspection personnel are in the pipeline. For CCTV inspection, videotapes are taken back to the office and viewed on a TV monitor. The technician then records the defects on form sheets. Although there appears to be no common rating method, many seem to be at least partially based on the methodologies prescribed by the Water Research Centre (WRc) [36].

All sewer failures can be attributed to either hydraulic or structural causes. Hence, any condition rating system developed for sanitary sewer pipelines must contain two key components: hydraulic and structural condition assessment.

6.4.1 Hydraulic Condition of Sanitary Sewer Pipelines

Hydraulic condition assessment is a means of determining if the system is capable of carrying the flows that are typically encountered without pressurizing or surcharging the system. Pressurizing or surcharging a sanitary system will often lead to flooding of connected units with sewage. Surcharging creates a cycle of exfiltration and infiltration, which increases the rate of deterioration of the pipeline system.

Surcharging of the sanitary sewer can lead to citizen pressure to upgrade the sewer, before the end of its structural life span because it can cause flooding of connected units. If the surcharging is not creating backups, or overflows into storm sewer systems or the surface, it is likely that the sewer will be allowed to operate as is until structural degradation requires its replacement.

A number of computer software programs that model the hydraulic condition and capacity of sewer systems are currently available in the United States.

6.4.2. Structural Condition of Sanitary Sewer Pipelines

Unlike the hydraulic condition of sewers, there has been little work done in the United States on the structural condition evaluation of sewer pipelines. In European countries, such as Germany and the United Kingdom, significant research has been conducted on the evaluation of the condition of sanitary sewer pipelines. In fact in 1996, Germany implemented an environmental law called Wasserhaushaltsgestz [37], which stipulates that leaking sewage systems are a crime.

6.4.2.1 Water Research Centre Method [36]

The WRc in England has developed guidelines for the evaluation of pipeline structural condition. It appears that they have carried out the most extensive research on the subject of the structural failure of sewers within the English speaking countries of the world.

During a period of five years, beginning in 1978, The WRc conducted research projects, valued at over 18 million dollars, into various aspects of sewer failure. WRc conducted sewer collapse investigations at over 250 sewer collapse sites. They also witnessed and documented the conditions found when several sewers, determined to be on the verge of collapse, were excavated and replaced. When these intact but poor condition sewers were excavated, WRc researchers examined the external condition of the sewer pipeline and the condition of the soil structure immediately surrounding the defective sewer pipe.

Following their fieldwork, WRc researchers conducted various laboratory and theoretical studies to identify the failure modes that were witnessed in the field. The WRc concluded from their research that the process of sewer collapse could be divided into the following three stages: initial defect, deterioration and collapse.

The WRc has used their research to develop a method for documenting the structural defects obtained from CCTV and man entry inspections. Recorded defects are then used to develop condition ratings for sewer pipelines. The WRc manuals are proprietary; therefore the methods contained within cannot be divulged within this paper.

6.4.2.2 Vani Kathula's Condition Rating Method [34]

Vani Kathula at Louisiana Tech University developed one of the more thorough condition coding procedures that has been done in the United States during her Masters of Science and Ph.D. thesis' preparations. Kathula's coding system is based on five failure mechanisms. The failure mechanisms are as follows: cracks, open joints, displaced joints, corrosion, and deformation. Table 6.1, details how Kathula codes the different defects found in sanitary sewers.

Table 6.1: Vani Kathula Condition Coding System

Pipe Defect	Severity Level	Abbreviation
Cracks	Tight Crack	TC
	Open Crack	OC
	Multiple Open Cracks	MOC
	Multiple Open Cracks + Small numbers of holes	MOC+H1
Open Joints	Small Open Joints	SOJ
	Medium Open Joints	MOJ
	Large Open Joints	LOJ
Displaced Joints	Small Displaced Joints	SDJ
	Medium Displaced Joints	MDJ
	Large Displaced Joints	LDJ
Corrosion	Light Corrosion	LC
	Medium Corrosion	MC
	Severe Corrosion	SC
	Severe Corrosion + Large number of Holes	SC+H2
Deformation	Light Deformation	LD
	Medium Deformation	MD

6.4.2.3 Modified Vani Kathula's Condition Rating Method

By incorporating the defect measurement criteria established by the WRc sewer condition manual [36], Serpente [33], and the use of engineering judgement one can develop a condition coding system that is easier for the user to discern the different defect severity levels. Table 6.2, illustrates how incorporating the defect measurement criteria of the WRc and engineering judgement can improve the Kathula coding system.

Table 6.2: Modified Vani Kathula Condition Coding System

Pipe Defect	**Severity Level**	**Abbreviation**
Cracks	Tight Crack	TC
	Open Crack	OC
	Multiple Open Cracks	MOC
	Multiple Open Cracks + Small numbers of holes	MOC+H1
Open Joints	Small Open Joints (Opening < 0.5t {t= pipe wall thickness})	SOJ
	Medium Open Joints (Opening <1.5t	MOJ
	Large Open Joints (Opening >1.5t)	LOJ
Displaced Joints	Small Displaced Joints (Opening >0.5t)	SDJ
	Medium Displaced Joints (Opening <1.5t)	MDJ
	Large Displaced Joints (Opening>1.5t)	LDJ
Corrosion	Light Corrosion	LC
	Medium Corrosion	MC
	Severe Corrosion	SC
	Severe Corrosion + Large number of Holes	SC+H2
Deformation	Light Deformation <10%	LD
	Medium Deformation >10%	MD

6.5 Condition Rating of Sanitary Sewer Pipelines

Once a condition coding system has been established, one must develop a numerical value that corresponds to the observed defects, in order to assign a condition rating to the pipeline.

The following is an example condition rating system that one could easily utilize:

1 – Excellent condition, no defects present.
2 – Good condition, only low risk defects present.
3 – Fair condition, pipe contains medium severity defects.
4 – Poor condition, pipe contains high severity defects and collapse is imminent.
5 – Failure condition, pipe is no longer functioning and is not structurally intact.

Table 6.3 shown below was created using engineering judgement concerning the severity level of various defects. As such, the severity of the defects varies somewhat from that which has been suggested by Kathula.

Table 6.3 Modified Vani Kathula Condition Coding System Incorporated with a Condition Rating System

Defect	**Excellent**	**Good**	**Fair**	**Poor**	**Failure**
Cracks	Intact	TC, OC	MOC	MOC+H1	Collapse
Open Joints	Intact	SOJ,	MOJ	LOJ	Collapse
Displace Joints	Intact	SDJ	MDJ	LDJ	Collapse
Corrosion	Intact	---------------	LC, MC	SC, SC+H2	Collapse
Deformation	Intact	---------------	---------------	LD, MD	Collapse
Rating	1	2	3	4	5

Once a condition rating has been assigned to a particular pipeline, the worst defect present is used as an indication of the overall sewer condition rating. Although the pipeline may not be in poor condition throughout its length, the worst condition along the length dictates its risk of collapse.

6.6 Case Study on Condition Rating System

We used the modified Vani Kathula condition rating system on two different sanitary sewer pipelines in the City of Minneapolis, Minnesota. The Department of Public Works division of sewer maintenance provided several CCTV videotapes of their system. Both of the sewer pipelines we selected had tapes available from two separate inspections conducted six years apart. The evaluated pipelines were located in Northeast Minneapolis on Fillmore Street North East from Saint Anthony Parkway to 30th Avenue North East and McKinley Street North East from 36th Ave North East to 35th Ave North

East. The results of these CCTV inspections and the resultant condition rating are shown in the appendix.

6.7 Summary

By establishing and implementing a condition rating system for sewer pipelines engineers can better manage the infrastructure. The ability to determine the condition of a sewer pipeline can aid the engineer in deciding what type(s) of rehabilitation techniques to apply. By knowing the condition of the sewer pipeline the engineer can schedule routine maintenance, rehabilitation, or replacement.

By implementing a standardized method of assessing the condition of sewer pipelines, one agency could compare the condition of their sewer assets to those of another agency.

Although currently the most cost-effective method for determining the condition of sewer pipelines is to use CCTV and the Visual Evaluation Method, the future holds many promising possibilities. As technologies continue to advance in the area of responsive type devices, such as PIRAT (Pipe Inspection Rapid Assessment), great changes may occur in the way condition assessments of sewer pipelines are made.

In the next chapter, the modeling of how an asset progresses from one Condition State to the next will be discussed.

CHAPTER SEVEN:

DETERIORATION MODELING

7.1 Objectives

As noted in chapter three, one of the key components of an asset management system is the ability to predict the infrastructure's future performance. To determine infrastructure's future performance and needs, one must be able to predict how the system will age given its current condition. In this chapter, methods that can and have been used in modeling and predicting the future performance of the infrastructure systems will be discussed. The discussion below is a synthesis of material taken from the following references: [34], [38] - [48], [50], and [52] – [54].

7.2 Definition of Deterioration Modeling

A deterioration model is a tool that predicts future asset condition and performance. In particular, this chapter will focus on the deterioration of sewer pipelines.

7.3 Background of Deterioration Modeling

The aging of sewer pipelines and the corresponding deterioration that take place during the life of a pipeline are complicated processes that are affected by an extensive amount of variables. As such, the life span prediction of pipelines cannot be easily determined. The prediction of pipeline aging can be formulated though the combination of probability based equations, and empirical data based on the evaluation of existing pipelines over their life span.

7.3.1 Definition of Deterioration Models [38], [39]

Descriptive Model - A model that approximately reproduces input/output responses for the available experimental data. It could be empirical or mechanistic.

Mathematical Model - A set of equations that describe the conceptual model in mathematical terms. The mathematical model can be either deterministic or stochastic.

Deterministic Model - A mathematical model that contains no random components. Each component and input is determined exactly by mathematical equations.

Stochastic Model - A mathematical model which contains random components or inputs; for any specified input scenario, the corresponding model output variables are known only in terms of probability distributions.

Empirical Model - A model determined by statistically fitting equations to experimental data. May model conditions that appear to be connected, when in fact they are not. This model is in contrast to a mechanistic model.

Mechanistic Model - A representation of material properties, i.e. physical, biological. Based on a primary response parameter such as distress or deflection. This model is in contrast to an empirical model

7.4 Purpose of Deterioration Modeling

To optimize the reliability of a sewer system, and minimize maintenance costs, it is necessary to develop deterioration models for the sewer network. Deterioration models can assist in the prediction of future failures within the system. The ability to forecast sewer failures is helpful for the following reasons:

1. Future sewer rehabilitation and/or replacement can be better planned to avoid failures.
2. Prediction of future expenditures can be improved.

7.5 Procedure for Developing a Sewer Deterioration Model

A successful deterioration model must incorporate the following:

1. Data collection.
2. Data analysis.
3. Establish minimum acceptable condition levels.
4. Prediction of remaining service life.
5. Determine rehabilitation requirements.

7.5.1 Data Collection

At a minimum, one needs to collect or estimate the following data to develop a sewer deterioration model [41]:

1. Age.
2. Material composition.
3. Shape and size of conduit.
4. Slope of pipe.
5. Surrounding soil structure.
6. Depth of cover.
7. Location of water table.
8. Construction costs.
9. Existing condition.
10. All previous condition assessments.
11. Superimposed live and dead loading.
12. Maintenance history.
13. Sewage make-up and volume.

7.5.2 Data Analysis

The logical assumption is to use the condition versus age data collected for sewer systems to create a regression model of prediction. Trend analysis of the data will show that the conditions of older systems are in generally worse condition than newer systems.

Regression analysis is a process in which all inputs are determined exactly through the use of mathematical equations. To use regression analysis, one must assume that sewer pipelines deteriorate at a predetermined rate and that the selection of repair options is set. The assumption that sewers deteriorate at a predetermined rate is not valid for several reasons. Sewers that were constructed with poor quality materials require rehabilitation sooner than older sewer pipelines. In addition, there are a number of hydraulic and structural influences that can affect the deterioration rate of sewers differently. Hence, sewers will age faster or slower depending on various influences to which they are subjected.

To best improve a sewer’s condition, the engineer must choose between many different repair methods. Due to the wide range of deterioration causes and repair options, one can easily conclude that the deterioration rate and the selection of repair methods for sewers are random processes. The best way to model random occurrences is to use a probability based or stochastic model.

7.5.3 Establishment of Minimum Condition Level

One must first define a minimum acceptable condition level. By establishing a minimum condition level, one can predict in what year the sewer will need to be rehabilitated or replaced. For example, if a recent CCTV inspection analysis determines that the current condition rating of a given sewer is condition level four (see section 6.5) a deterioration model should be able to predict how long it will take the sewer to progress to deterioration level five.

7.5.4 Prediction of Remaining Useful Life

A deterioration model must be able to predict the remaining useful life of the sewer. Only after the remaining useful life has been determined, can one decide when to repair or replace a sewer.

7.5.5 Determination of Rehabilitation Requirements

The calculation of the remaining useful life is then used to fix rehabilitation requirements in time. By knowing when to rehabilitate or replace various sewers, engineers will be able to establish an accurate long-term maintenance and financial planning program.

7.6 Modeling Methods

The aging and deterioration of sewer systems is probabilistic [34], [41]. Therefore, in order to interpret observational data and use it as a basis for future system predictions, it is necessary to employ a probability-based technique. There are two probability-based models that lend themselves to solving this type of problem. The models are the Markov Chain and Cohort Survival [42]. These two models are discussed below.

7.6.1 Markov Model

The Markov model is named after the Russian Mathematician Andrei Markov. Markov models have been used to model condition deterioration phenomena in which the following holds true:

1. There exist a finite number of condition states for sewers.
2. The future condition of the sewer depends only on its present state.
3. A sewer can be in one of several numbered condition states and passes from one state to another during each time step according to fixed probabilities.

When Markov is used to model sewer deterioration in state i, there is a fixed probability, P_{ij} that the sewer will be in condition state j during the next time step t+1 [34], [39], and [41]. The term P_{ij} is called a transition probability. The transition of a sewer pipe from one condition state to the next is a function of numerous influences such as structural condition, construction materials, construction quality, and the many environmental factors which affect the pipelines deterioration rate.

A Markov transition matrix for sewer pipelines takes the form of Table 7.1. In the matrix, P represents a given sewer pipeline. P_{ij} represents the probability of the sewer passing from one condition state to the another during the next time period, where i , j = 1,2,…,m. Each probability P_{ij} is greater than 0 and less than or equal to 1. The sum of the probabilities of each individual row is always equal to one. The entry of 1 in the last column and row of the transition matrix P indicates that there is no probability of the sewer pipe leaving this condition state.

Table 7.1 A Typical Five Condition State Markov Sewer Matrix

P =

p_{11}	p_{12}	p_{13}	p_{14}	p_{15}
0	p_{22}	p_{23}	p_{24}	p_{25}
0	0	p_{33}	p_{34}	p_{35}
0	0	0	P_{44}	P_{45}
0	0	0	0	1

The Markov Chain matrix requires us to determine state transitions for every possible condition state possible over the time period examined. Once these transition probabilities for the time step in question are determined, the Chapman-Kolmogorov equation allows the computation of the transition probabilities for any time step desired.

7.6.1.1 Chapman-Kolmogorov equation: $P^{(n)} = P^n$ [34], [39], [41]

The n-step transition probability matrix ($P^{(n)}$) is obtained by taking the n-th power of the one step transition matrix (P^n). For example, if we determined the 5-year transition probability matrix from observational data, we can use this matrix to determine the probability condition matrix for any length of time step through the use of the Chapman-Kolmogorov equation. The 10, 15, 20…100 year transition probability matrices are simply P^2,P^3,P^4,…, P^{20} respectively.

7.6.1.2 Markov Transition Probabilities

To successfully apply the Markov Chain Model, one must determine the sewer condition state transition probabilities [34], [39], [41]. These transition probabilities can be estimated by analyzing the deterioration curves for each sewer type. To get the most accurate transition probabilities, it is necessary to group the pipelines according to the common characteristics that most greatly affect the life span of sewer pipelines. Deterioration curves should then be generated for each sewer group. An example of one type of sewer group could be one that contains clay pipes, surrounded by non-cohesive soils, located above the water table, on a local street, with no surcharging. The deterioration curves should be generated based on historical sewer records.

7.6.1.3 Prediction of Future Condition [39]

Once all of the transition probabilities have been determined for the Markov Chain model, it can be used to predict the future condition makeup of sewer pipelines. The following equation is the work of D.M. Abraham and R. Wirahadikusumah and it is used to determine the predicted condition state of a sewer:

$$E[X(t=n, P)] = [1\ 0\ 0\ 0\ 0\ ]\ P^{(n)}\ [1\ 2\ 3\ 4\ 5]^{t}$$

where:
E = predicted condition rating
n = number of time periods
[1 0 0 0 0] = initial condition state matrix
$P^{(n)}$ = condition state transition matrix
[1 2 3 4 5] = condition state matrix

7.6.1.4 Vani Kathula's use of Markov to Model Sewer Deterioration [34]

If historical data is not available, it is possible to develop the transition probabilities from expert opinion. Vani Kathula and other researchers have found expert opinion to provide good transition probability values. Vani Kathula used expert opinion to construct a complete structural condition matrix (SCM) for each type of defect listed in Table 6.2. Vani Kathula's system of Markov deterioration matrices enable a person to estimate the percentage of pipelines that would be in different condition states after a certain number of years of life have passed. Due to incomplete agency data, Kathula was unable to validate her model by comparing it to CCTV inspection data.

7.6.1.5 Summary of the Markov Method

As can be seen from the preceding explanation of the Markov method for sewer condition prediction, the method is data intensive. In addition, the computation of accurate transition probabilities will be crucial to the prediction abilities of the model. These transition probabilities should be calculated through the use of condition ratings determined through the actual inspection of the sewer system in question. As more municipalities begin to take on a forward-thinking sewer management program, the transition probabilities will become more readily available. Computer software will need to be developed for the Markovian approach before most engineers will consider using this method to manage their sewer system.

7.6.2 Cohort Survival Model [42]

Cohort survival models are used to make predictions about future population numbers. Demographers use mortality and fertility data in order to construct the cohort survival model. A cohort corresponds to a group of individuals that were born during a certain time period. The demographer uses age and gender specific death rates to calculate the number of survivors within each of the cohort age groups.

The Infrastructure lifecycle process can be thought of in a similar way to that of humans. Infrastructures, such as sewer pipe, are born on the day that they are constructed. At that time, the processes of aging and decay begin. Eventually the sewer will fail. This corresponds with death in the human cohort model. Deaths in human population are replenished by the natural reproduction of its members. Infrastructure on the other hand is replaced through new construction, rehabilitation, or reconstruction. These replacements require capital outlay. As with social planning that occurs with human population prediction, it is helpful for infrastructure managers to be able to plan on when these capitol outlays will occur.

7.6.2.1 Herz Survival Function

Professor Raimund Herz of the Dresden University of Technology in Germany has approached the problem of pipeline aging and deterioration in a manner similar to that used by population researchers. Professor Herz has developed the Herz Distribution by equating pipelines to populations and grouping them by construction dates. The formula that Herz has developed to model the remaining useful life of a sewer is as follows [42]:

Herz Survival Function: $y(x) = 1-F(x) = (a+1)/(a+e^{b(x-c)})$

Where,

F(x) = The integral of f(x) or the summation of the sewer failures that have occurred since the date of construction (birth) of the group or cohort.

f(x) = The proportion of sewers that fail in any given year.

a = Aging factor, an empirical parameter that affects the speed at which sewers start aging. The greater “a” the slower the start of the aging process

b = Failure factor, an empirical parameter that affects the rate at which the sewer ages. The greater “b” the faster the aging process.

x = Age of sewer

c = Resistance time or the elapsed time from construction to the first observed sewer failure of the group.

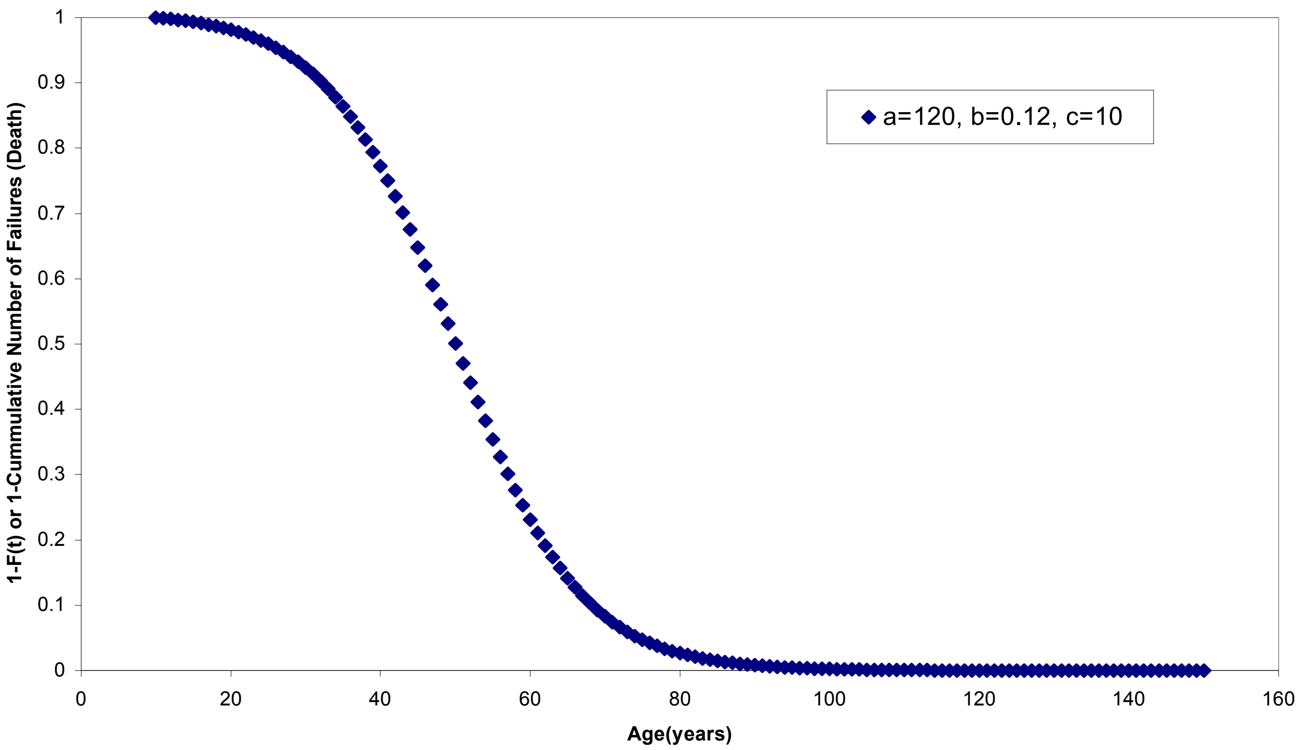
When $x \geq c$, $y(x) = 1-F(x) = (a+1)/(a+e^{b(x-c)})$

When $x < c$, $y(x) = 1-F(x) = (a+1)/(a+e^{b(x-c)}) = 1$

The Herz Survival function determines the expected proportion of sewers that are still functioning at the end of each year. Figure 7.1, is Herz Survival Function for a cohort of sewers. The parameters a, b, and c, were arbitrarily chosen and are listed within the graph. The graph depicts the proportion of surviving sewers as a function of age.

The Survival function can be extracted from real life observations of sewer pipeline segments. Regression techniques are used to fit the distribution of the proportion of surviving sewers by varying the aging parameters a, b and c of the Herz distribution.

Figure 7.1 Herz Survival Function

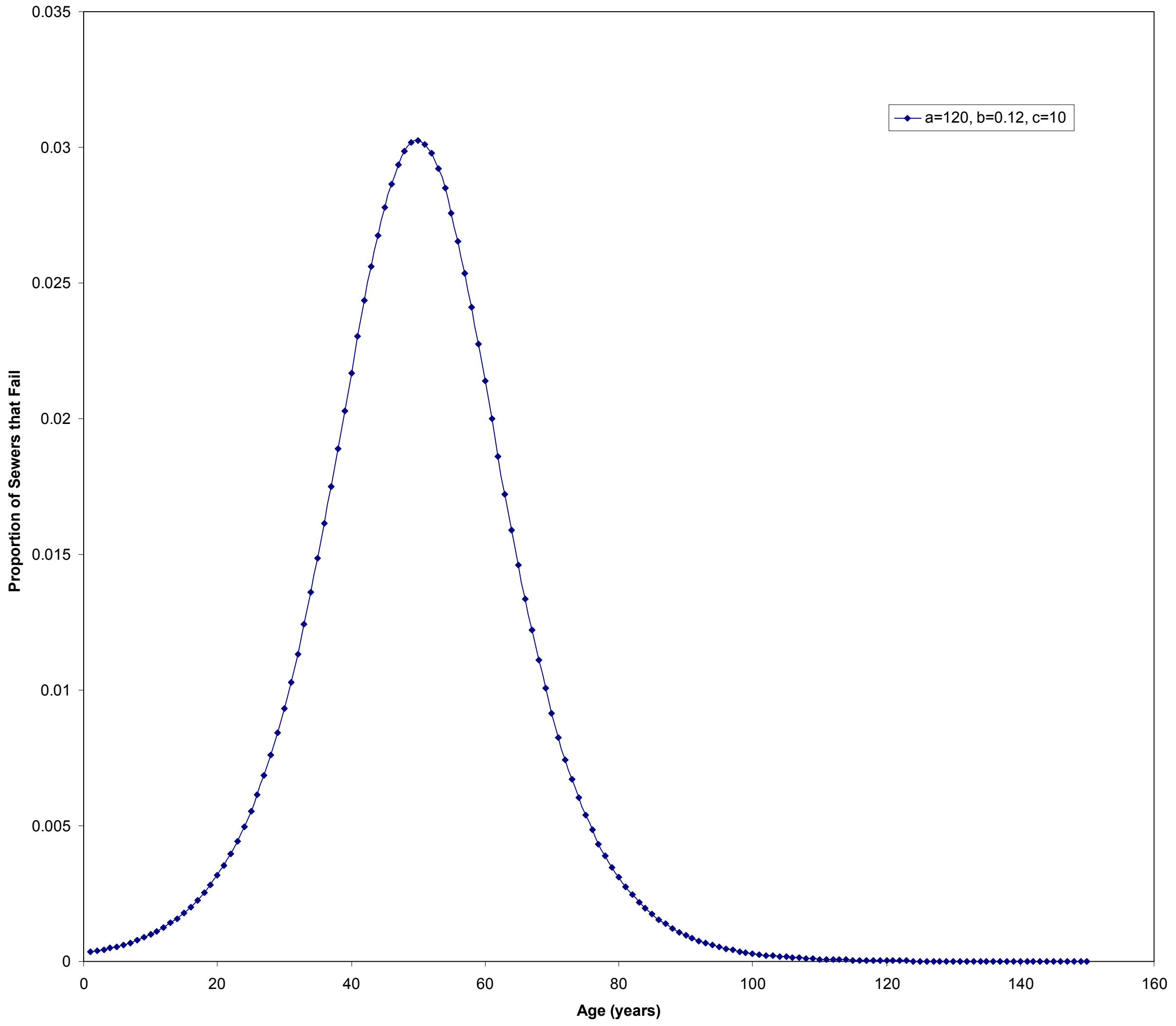


7.6.2.2 Herz Service Life Density Function

Once the aging parameters have been determined for a particular pipeline cohort, the Service Life Density Function, the rehabilitation rate and the residual service life expectancy can be obtained.

The Herz Service Life Density Function can be determined by taking the first derivative of the Herz Survival function. The service life density function is given as $f(x) = (a+1)be^{b(x-c)}/(a+e^{b(x-c)})^2$. The service life density function represents the proportion of sewers that fail each year. Figure 7.2 illustrates the Service Life Density Function for the Survival Function given in figure 7.1.

Figure 7. 2 Herz Service Life Density Function



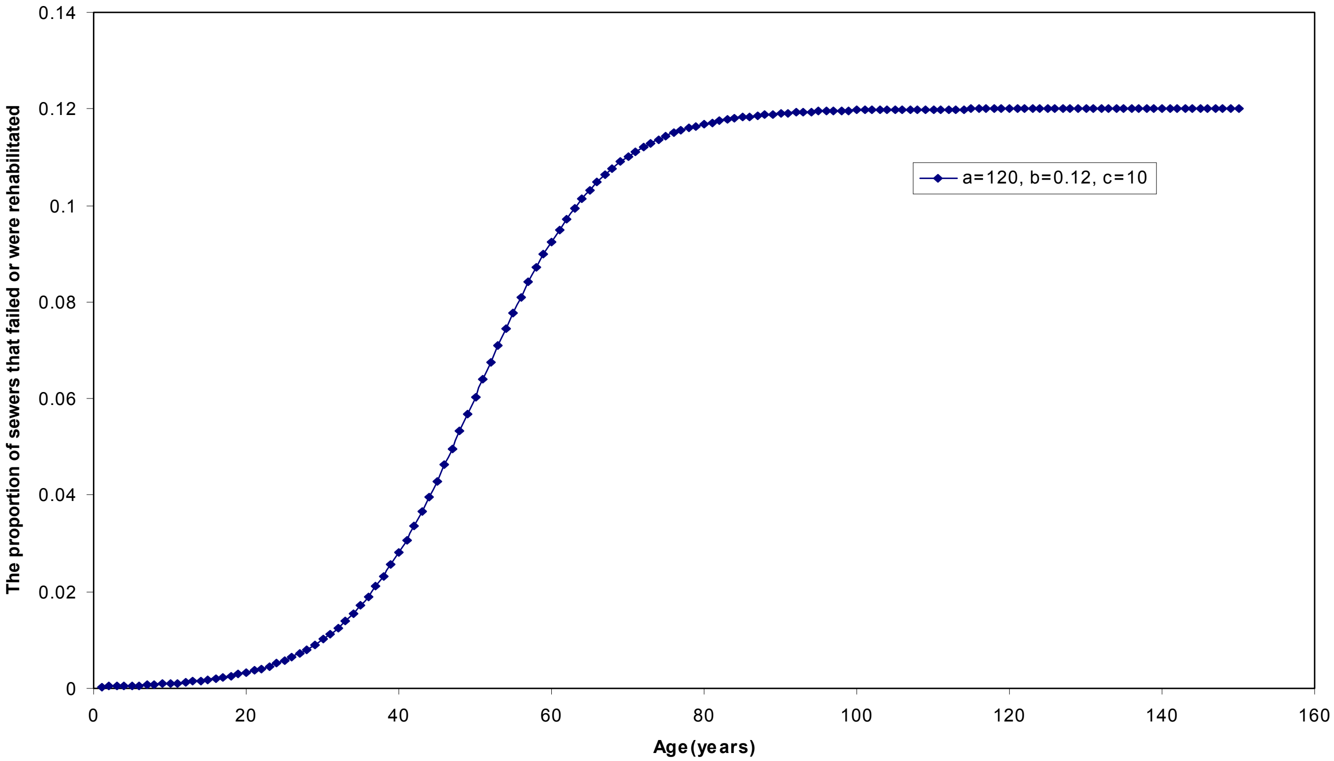
7.6.2.3 The Herz Failure or Rehabilitation Rate

The failure rate represents the proportion of sewers that fail each year, in relation to the number of remaining intact sewers. The rehabilitation rate corresponds to the proportion of sewers that must rehabilitated each year due to failure. Hence, one can conclude that the rehabilitation rate is equivalent to the failure rate.

Therefore, by combining the service life density and the survival function, one can determine the amount of resources that will be required to repair and maintain the system in a given year.

The failure or rehabilitation rate is determined by dividing the service life density function, f(x), by the survival function, 1-F(x). Simplifying, the rehabilitation rate in any year is given as $Z(x) = be^{b(x-c)}/(a+e^{b(x-c)})$. Figure 7.3 is a plot of the rehabilitation/failure rate for the Herz Distribution, which was plotted in Figure 7.1

Figure 7.3 Herz Rehabilitation or Failure Rate



7.6.2.4 The Herz Remaining Life Expectancy

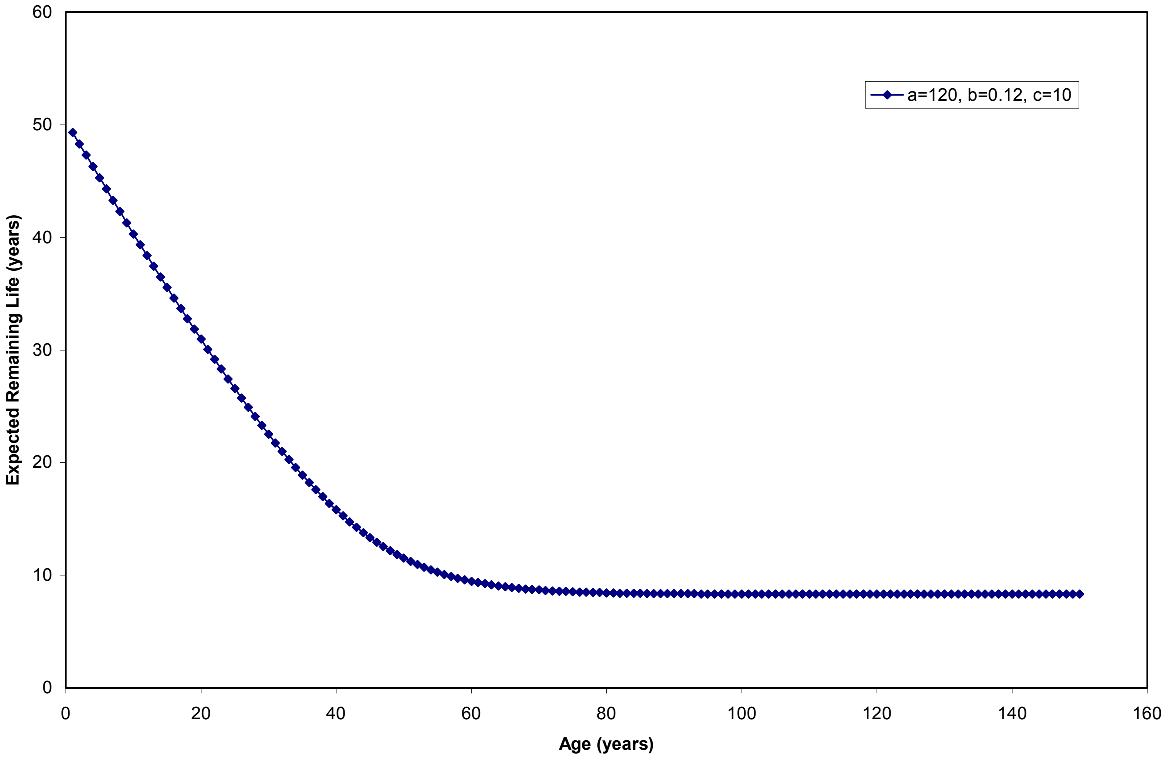
The remaining life expectancy of a pipeline can be determined from the Herz Distribution and is represented by the following equations:

$$R(x) = ((a+1)\ln(a+1))/ab. \text{ for } x < c$$

$$R(x) = (a+e^{b(x-c)})[((\ln(a+ e^{b(x-c)})/ab)-(x-c)/a] \text{ for } x >= c$$

Figure 7.4 is a plot of the life expectancy for the Herz Distribution, which was plotted in Figure 7.1. As can be seen in Figure 7.4, the residual service life expectancy decreases linearly at first, but then at old age, it approaches an asymptotic value. The value approached is the inverse of the failure factor, 1/b.

Figure 7.4 Residual Service Life Expectancy



7.7 Application of The Herz Method to Condition Prediction

In the above equations and example plots, absolute failure, or death is depicted. It is possible to define several condition classes that exist within the time between construction and failure of the pipeline system [42].

The rating system described in Chapter 6 contained 5 condition states from 1 to 5. Condition State 1 corresponds to excellent condition with no defects present. At the opposite end of the condition spectrum is Condition Class 5, which corresponds to a pipe that has failed and is no longer able to carry out its required function. Transition into condition class 5 could be represented by the aging functions represented in the preceding examples. These functions represent the transition into a failed state. In a similar fashion, it is possible to determine the Herz Distribution parameters, a, b, and c associated with the transitions between the five defined classes.

The five-condition class system requires calculation of the following parameters:

Condition Class 1 to Condition Class 2	a_1	b_1	c_1
Condition Class 2 to Condition Class 3	a_2	b_2	c_2
Condition Class 3 to Condition Class 4	a_3	b_3	c_3
Condition Class 4 to Condition Class 5	a_4	b_4	c_4

An arbitrary example of the aging parameters for a 5-condition class system is as follows:

Condition Class 1 to Condition Class 2	$a_1 = 50$	$b_1 = 0.25$	$c_1 = 2$
Condition Class 2 to Condition Class 3	$a_2 = 60$	$b_2 = 0.20$	$c_2 = 5$
Condition Class 3 to Condition Class 4	$a_3 = 90$	$b_3 = 0.16$	$c_3 = 8$
Condition Class 4 to Condition Class 5	$a_4 = 120$	$b_4 = 0.12$	$c_2 = 10$

The plot of the Herz Survival Function and Herz Service Life density function for these aging parameters is shown in Figures 7.5 and 7.6.

Figure 7.5 Herz Survival Functions for Five Condition Classes

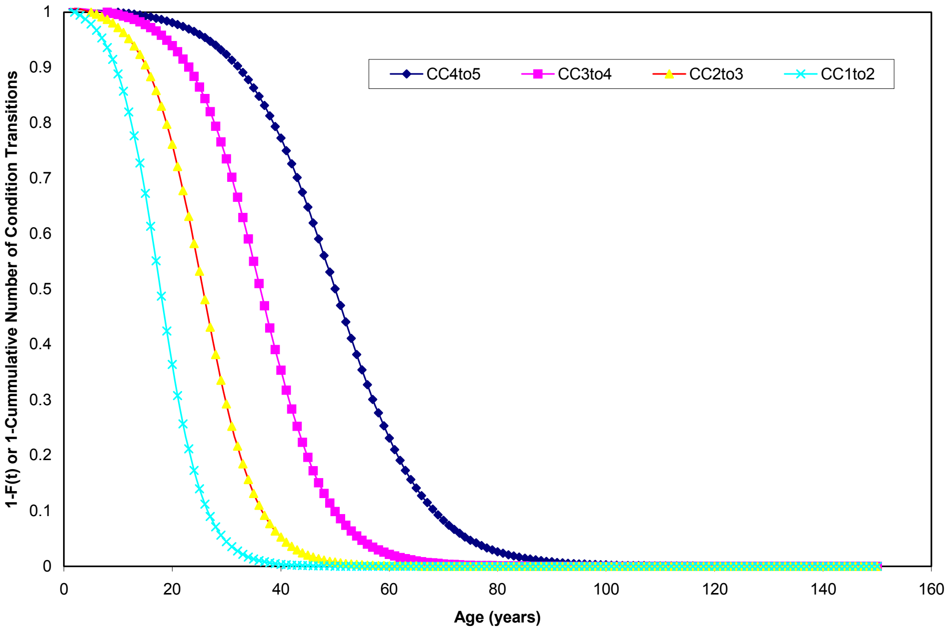
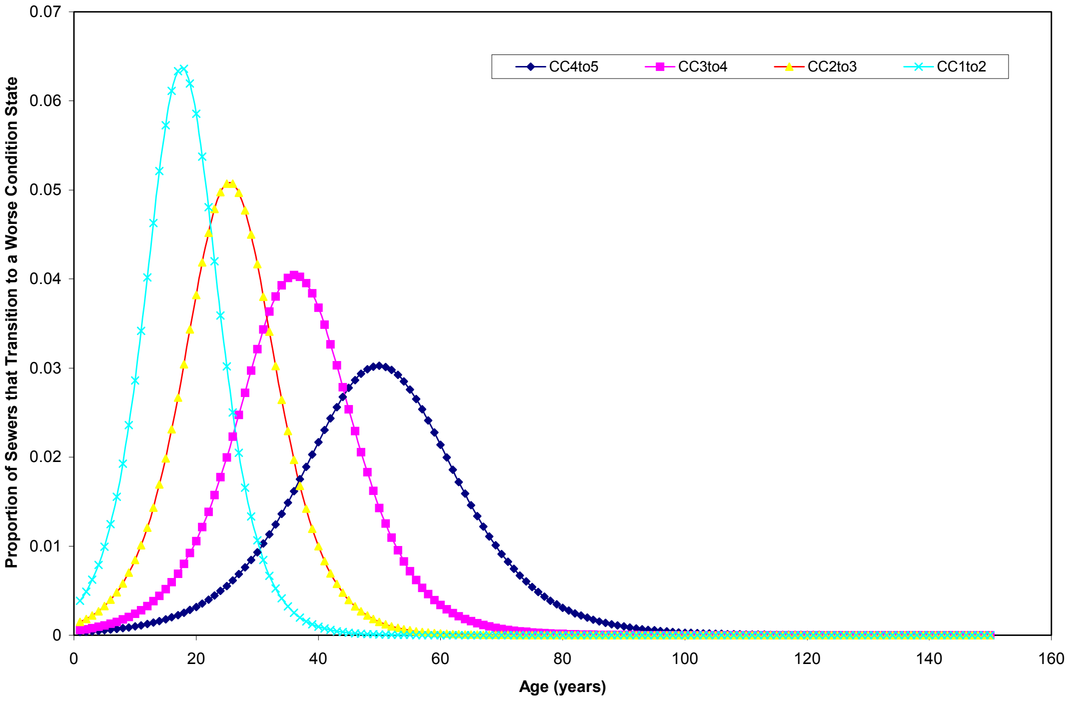


Figure 7.6 Five Condition Class Service Life Density Functions



Similar plots could be made for the rehabilitation/failure rate and the expected remaining residual life within each condition class. The rehabilitation rate may be selected based on a predefined minimum acceptable condition level. For instance, if an engineer selects condition class 4 as the minimum acceptable level, both the yearly rehabilitation rate and the expected remaining service life of a sewer could be predicted through the Herz distribution of condition class.

7.8 Determining the Aging Parameters for the Herz Method

Similar to the Markov Model presented earlier, which required estimation of the matrix transition probabilities, it is necessary to determine the aging parameters used within the Herz Distributions in an empirical manner. The aging parameters define the shape of the Herz Distribution and in turn provide age-condition information specific to individual sewer types.

As with Markov Deterioration modeling, when using the Cohort Survival Model, pipelines should be grouped according to characteristics that affect aging. By organizing the sewer types into like groupings, distribution curves with less variance will result, thereby increasing the accuracy of modeling efforts.

Ideally, the pipeline system being analyzed would be able to provide a substantial data set of age and condition observations from the system. Unfortunately, this is not usually the case. Pipeline systems have for the most part been neglected when it comes to monitoring the physical condition of it components. It therefore becomes necessary to estimate the values of the aging parameters. In the absence of statistically sufficient data sets, Dr. Herz recommends estimating the aging parameters by the following methods [42].

7.8.1 Method One for Determining the Aging Parameters

The resistance factor, c, is the time up until which there is no rehabilitation. The resistance factor should be within the range [42]: 10 yrs $\leq c \leq$ x-3s. The other two parameters, x and s, can be estimated by assuming a value for the mean useful life and the standard deviation. The parameter a can then be estimated from [42]:

$$(x-c)/s = \ln(a)/(p^2/2 + 2\ln(2)\ln(a))^{1/2}$$

The parameter b is then determined from:

$$b = \ln(a)/(x_{mean}-c)$$

7.8.2 Method Two for Determining the Aging Parameters

The age that is predicted to be reached by a certain percentage, p, of the population can be estimate from expert opinion. The aging parameters can then be determined from the following equations [42]:

$p=100\% \Rightarrow x_{100} = c$

$p=50\% \Rightarrow x_{50}=c+(\ln(a+2)/b)$

$p=10\% \Rightarrow x10= c+[(x_{50}-c)/\ln(a+2)][\ln(1+0.9a)-\ln 0.1]$

7.8.3 Validation of the Estimated Aging Parameters

Using the Herz Survival Function, one can check the accuracy of the estimated aging functions. The results predicted by the model can be compared to the conditions and failures observed within the actual system during past inspections. An easy way to check the accuracy of the parameter estimates is to plot the survivor function obtained with the estimates on the same plot as the lifetime data obtained through observation. This plot will enable the researcher to see if the parameters are close, or if adjustments are needed. The parameters are then adjusted accordingly to make the model fit past observational data.

7.8.4 Summary of Aging Parameters Estimation

The parameter estimation method outlined above is a trial and error method that allows the engineer to determine the best fit of the Herz Distribution Function. As more sewer data is gathered, it will be possible to estimate the parameters through techniques such as least squares estimation or other parameter regression methods.

7.9 Modeling Software

The equations and matrices necessary used in deterioration models require a massive amount of data for accurate prediction. The use of computer databases and software specifically for the purpose of deterioration model is vital to an asset management system for pipelines. Limited computer software programs based on the Markov Model are available. However, there are several programs available that are based on the methods of the Cohort Survival Model.

For sewer systems, Aqua-Ing [43] of Saarbruucken, Germany has developed the programs Aqua WertMin and Aqua Selekt. These programs are based on the Cohort Survival model. They include a decision support system for rehabilitation selection. Aqua Selekt is described as a selective (reduced) inspection-modeling program. It automatically groups sewers into the characteristic groups described in the Markov section above. Aqua-Ing claims to have 95% condition prediction accuracy available through Aqua Selekt, with only having to conduct inspections on 10% of the entire sewer system.

7.10 Summary of Deterioration Modeling

Both of the deterioration models described within this chapter are capable of accurately modeling the processes of pipeline deterioration. The Markov Model has its roots in the regression analysis of a condition versus age plot of the pipeline system data. The regression analysis fits a single curve through the many data points present, and thereby describes the deterioration expected by the majority of the pipelines within the system.

The Herz Distribution provides probability information regarding the length of time a sewer will spend within a given condition class and ultimately the amount of time it takes to fail. It includes all of the data contained within the Markov Model, by tracking the aging process of the 50th percentile of the distribution. The 50th percentile of the Herz Distribution is the mean age at the time a sewer transitions from one condition state to another or its transition to failure.

The Herz distribution provides more information to the researcher on the distribution of conditions within specific pipeline cohorts. The condition at age x is known for all possible probabilities. This enables the researcher to know when it is probable that a portion of the pipelines is moving into each condition class. Therefore, the Herz Distribution provides the engineer with more information that can be used to program follow up inspections for condition verification.

Both methods require empirical estimation of parameters vital to their prediction methods. As condition inspection and data records increase, the estimation of these parameters will become more accurate and more useful for both of the models.

The previous chapters of this paper have described the reasons that deterioration modeling is vital to life cycle costing. Another piece of information that is provided by the models will be the performance that can be expected for different materials used in the construction of pipelines. This information will enable engineers to choose the best material available for new installations and for the rehabilitation or replacement of existing facilities.

The next chapter will tie this paper together and present overall conclusions and recommendations for further work.

CHAPTER EIGHT:

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

Under the auspices of public accountability, the GASB 34 requirements are shedding light on the current lack of knowledge regarding the condition of the built environment that surrounds us all. The requirements of GASB 34 will undoubtedly cause engineers to reconsider their approach to infrastructure construction, maintenance, rehabilitation, and replacement. GASB 34 requirements will force engineers to become accountable for new infrastructure projects on a “cradle to grave” basis.

Agencies will have to choose between the depreciation method and the modified approach of GASB 34. The modified approach will facilitate the development of infrastructure management tools to assist with the allocation of scarce resources. Agencies that choose the modified approach to GASB 34 can document compliance with minimum condition levels by implementing an asset management system. The use of an asset management system will allow engineers to make improved project and system level decisions.

Once an agency has inventoried their entire infrastructure and developed an asset management system, they can use life cycle cost analysis to choose the most appropriate maintenance activity resulting in the greatest benefit. Life cycle cost analysis, in which a project’s net present value is determined, should be used for all decisions related to infrastructure design, construction, operation, maintenance, and rehabilitation alternatives.

An essential component to infrastructure asset management is the development of a consistent and repeatable condition rating system. Several different methodologies can be used to determine the condition of an infrastructure asset. The establishment and implementation of a condition rating system for sewer pipelines is paramount for better management. Sewer condition assessment rating can aid engineers in deciding when rehabilitation is warranted and what type of rehabilitation techniques to apply. Lastly, the implementation and development of a nationwide standardized method of condition assessment must occur before agencies can be compared to one and other.

Researchers at Purdue University and Louisiana Technological University have used the Markov technique to develop condition prediction models. Research on deterioration modeling of pipelines is in its early stages, in the United States.

Researchers at the University of Desden, Germany have used the Cohort Survival Function in conjunction with the Herz Distribution method to develop condition prediction models. The German Company Aqua Ingenieure has developed a commercially available deterioration and inspection prediction model.

The Markovian and the Cohort Survival deterioration models are both equally capable of predicting the pipeline deterioration processes for different construction materials. Both models require empirical estimation of parameters vital to their prediction methods.

In light of increasingly scarce resources, the old “fail-fix” replacement strategies are becoming cost prohibitive. Many studies have shown that neglecting regular maintenance of underground utilities increases life cycle costs, user inconvenience, and public safety. In light of ever-increasing public scrutiny, engineers are being tasked with specifying the most cost effective pipeline installations, maintenance, and rehabilitation techniques. As our county continues to age, engineers must continue to seek out new ways to manage the infrastructure that the public has assigned them to steward. Much research and study has been done on infrastructure management, but much more remains to be done. Cooperation is the key; engineers must begin to attack infrastructure management on a global level.

8.2 Recommendations

There is a strong need for new and improved management tools to help today's civil engineers develop new ideas and methodologies for replacement of the infrastructure. The following is a list of recommendations to improve GASB 34, Asset Management, Life Cycle Cost Analysis, Condition Ratings, and Deterioration Modeling:

GASB 34

- Agencies should fulfill the requirements of GASB 34 by following themodified approach.
- A standardized condition rating system should to be developed with a minimum acceptable level for all infrastructure assets. It should be universally followed by all agencies. This will lead to the ability to more accurately compare the financial standing of all agencies.
- The three-year GASB 34 condition assessment requirement for the modified approach needs to be reevaluated for long-lived assets. This requirement is far too stringent for new infrastructure. It should be relaxed, so that inspections can be done more frequently on older infrastructure and less frequently on newer infrastructure.
- GASB should be amended to include a method of predicting the future performance of the infrastructure and thus more closely follow an asset management system.

Asset Management

- Intertwine the asset management system and the agency's mission.
- Place high standards for the gathering of accurate and timely data.
- Ensure the asset management system is customer orientated.
- Garner and maintain political support.

Life Cycle Cost Analysis

- The engineer must decide the overall best design option based on the project's net present value.
- Life cycle cost analyses must be consistent and repeatable.

- More work on user costs should be done and the results must be shared with all engineers so they can most accurately determine the true life cycle costs of all design options.

Condition Ratings

- A standardized method of assessing the condition of all infrastructure assets, especially sewer pipelines, should be adopted and utilized by all agencies.
- The condition rating method should be user friendly.
- The condition rating method should be easily adaptable to improvements in inspection technology.
- The European Standard for sewer condition and inspection, EN 752 should be considered for use in the United States of America.

Deterioration Modeling

- Once a standardized condition rating system is established and implemented, a research organization should be set up to collect all the condition data to further develop and improve the deterioration equations and curves that have been developed by Herz and/or the Markov method.
- The affects of maintenance to the sewer pipelines should be studied to determine how different maintenance activities change the deterioration rate of the pipeline.
- Researchers and engineers in the United States should explore further what has been done on this topic in other parts of the world. A better method of information sharing amongst engineers throughout the world should be established. Doing so would eliminate much duplicate research and thus lost time in the furtherment of understanding how infrastructure assets, particularly pipelines, deteriorate.

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