CHAPTER 1 - INTRODUCTION

1. 1 Motivation

Recent outbreaks of pinhole leaks nationally are a significant issue. Figure 1.1 shows the national distribution of pinhole leaks based on the data gathered by the Copper Development Association and Plumber's Survey conducted by Dr. Edwards (2004). In the major water distribution system managed by municipalities and water utilities the costs are distributed among all subscribers. However, home plumbing repair/replacement cost and possible water damage cost must be addressed by the homeowner. When a pipe has a corrosion hole, the homeowner is typically faced with the following issues: water damage cost, repair cost, service disruption, lowering of home value, home insurance premium increase, and health consequences such as resulting from brown mold growth and mental stress from both concentrated nature of individual repair damage costs and health effects. Home owners near the hot spot areas are considering additional treatment to water in terms of corrosion inhibition, different plumbing materials such as plastics and stainless steel, and coating the interior of the pipe. Homeowners are also seeking advice on whether to continue to repair or replace the plumbing system.

A repairable asset is considered to be in continued use but can be restored to a new state, better, about the same, or worse for a cost at the time of repair. Assume W_0 be the initial value of the home plumbing system and W_1 is its value after a corrosion incident with a repair/ replacement cost of R. The loss is therefore due to repair and the value lost $[R+ (W_0 - W_1)]$. Now, the same construct is repeated for N repairs accounting for proper discounting. At the N^{th} repair a decision has to be made whether to replace the system with an alternative or continue to repair it. This decision is obtained by minimizing the total discounted loss over N times. At each repair, the available alternatives are examined in place of retaining the old pipe. (Loganathan, MUSES proposal, 2002)

Also a decision on using other pipe material such as plastic, stainless steel, and copper with increased wall thickness has to be made. These different materials have to be considered for cost, consumer preference from the point of view of selling the house, corrosion susceptibility, strength, behavior in the case of a fire, and health effects. Different materials show different leak behaviors. These considerations are shown in Figure 1.2.

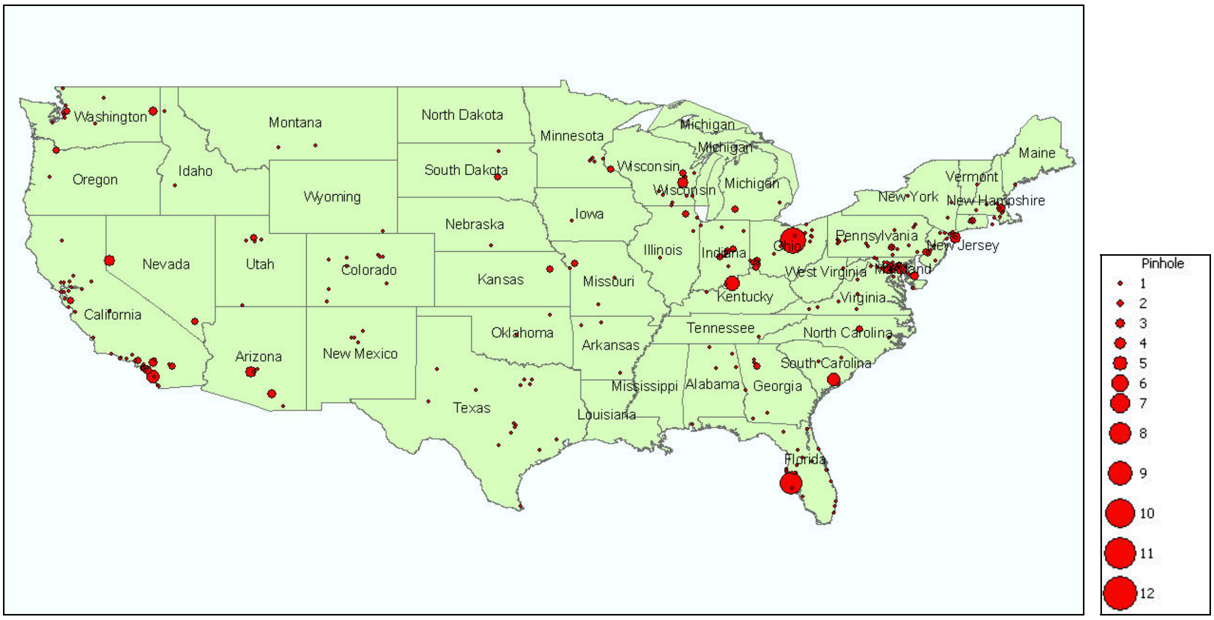

Figure 1.1 National distribution of pinhole leaks

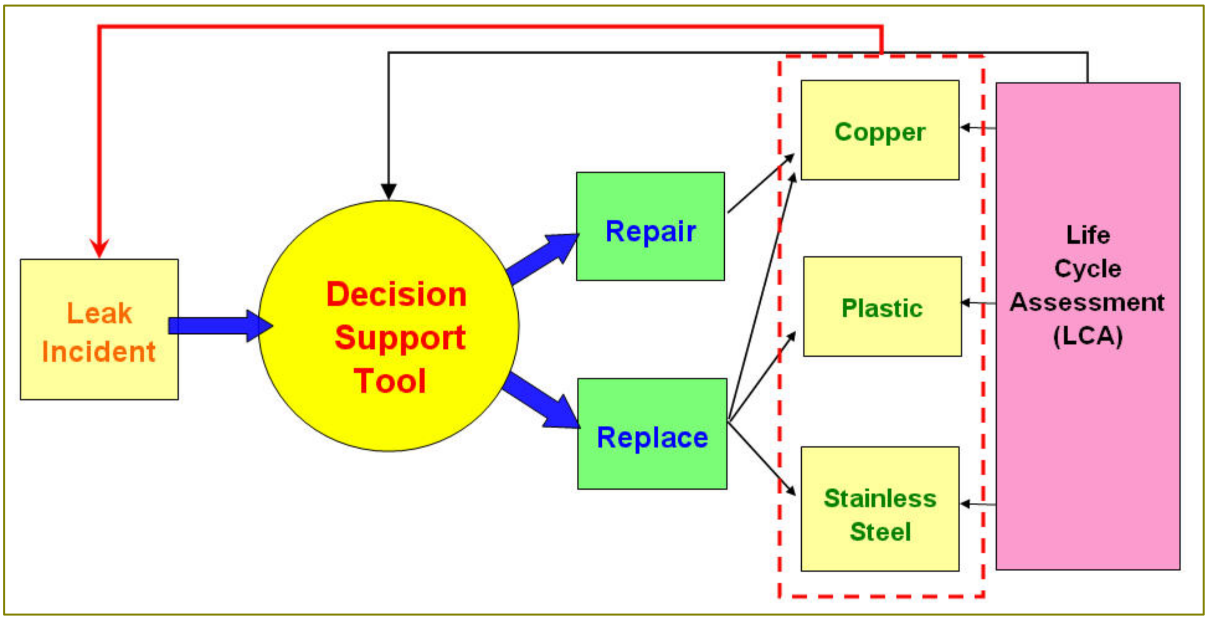

Figure 1.2 Decision making process

1. 2 Major System and Minor System considerations

Water distribution system is composed of a major system and a minor system. The major system brings treated water to the street level of homes and the minor system carries the water from street level mains into homes (Figure 1.3). Table 1.1 lists the major differences between the major and the minor systems.

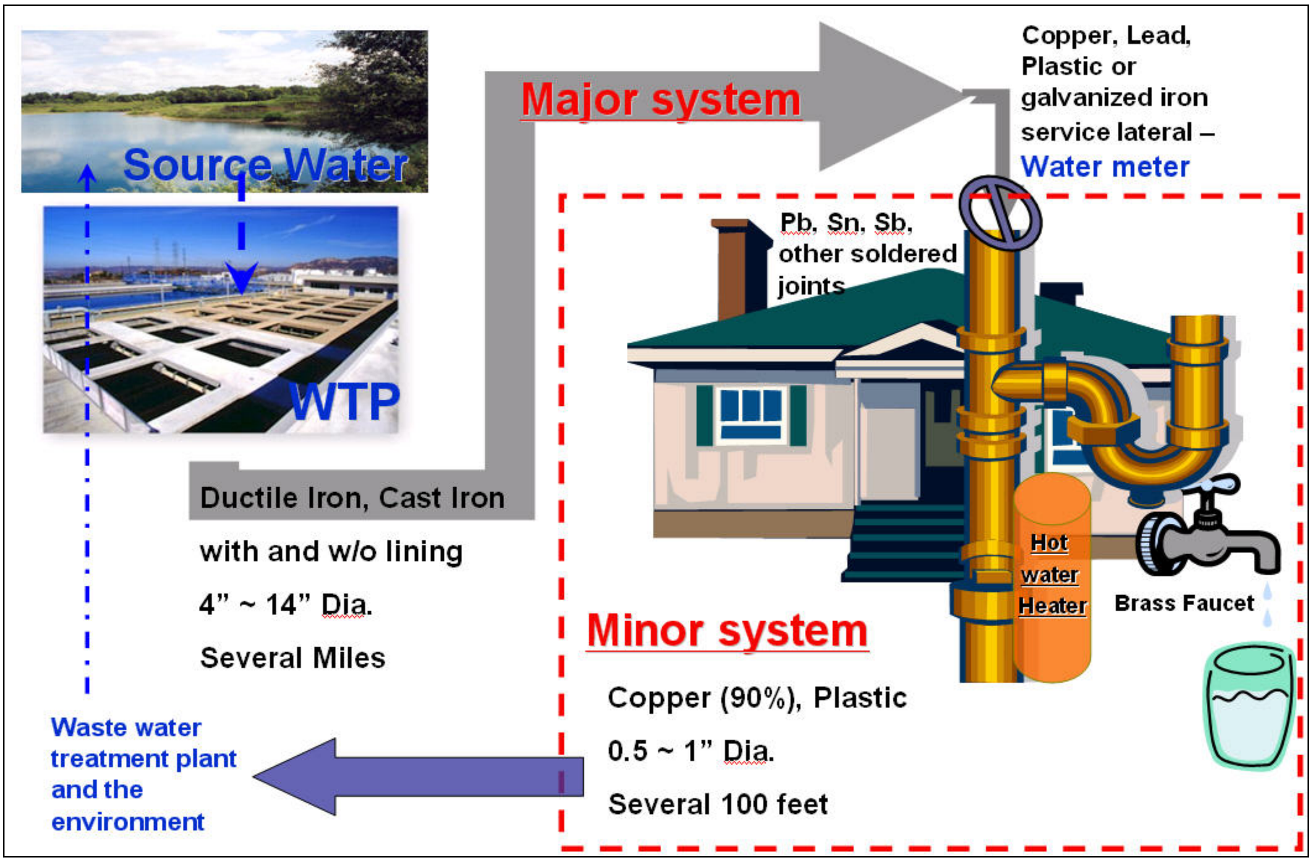

Figure 1.3 Major and Minor distribution system

Table 1.1 Characteristics of Major and Minor distribution system (Loganathan, 2002 MUSES proposal)

Characteristic	Major System	Minor System
Pipe diameter	4in – 14 in	½ in – 1 in
Pipe material	Ductile iron, Plastic, Cast iron	Copper, Plastic, Galvanized iron
Pipe length	In miles (10s to several 100s)	In feet (several 100s)
Pipe wall thickness	Ductile iron 6.6 mm and above	Copper: K 1.25 – 1.7 mm; L 1.02 – 1.3 mm; M 0.71 – 0.89 mm
Corrosion	Both internal and external	Internal
Velocity	3 to 6 ft/sec	~ 4 ft/sec
Life expectancy	Ductile iron ~ 80 years	Copper ~ 80 years; Galvanized iron 40 – 50 years
Ownership	Utility	End user (Homeowner, companies, industries)
Regulation	Government	
Cost	Distributed by water rate	Individual/insurance; Replace piping $4,000 - $6,000
Property damage	Distributed – few 100s to several 1000s in dollars	Few 100s to few 1000s in dollars
Service response	Immediate	Delayed
Customer Dissatisfaction	Marginal to serious	Serious
Availability of the data	Records kept – computerized	May not have records

In decision making process, consumers are influenced by various factors. First, the regulations and standards of the federal, state, and local governments have major impacts. These regulations influence plumbers, material producers, insurance companies, and water utility companies; consequently, consumers are influenced by all of the above service providers. Figure 1.4 shows these overall relationships.

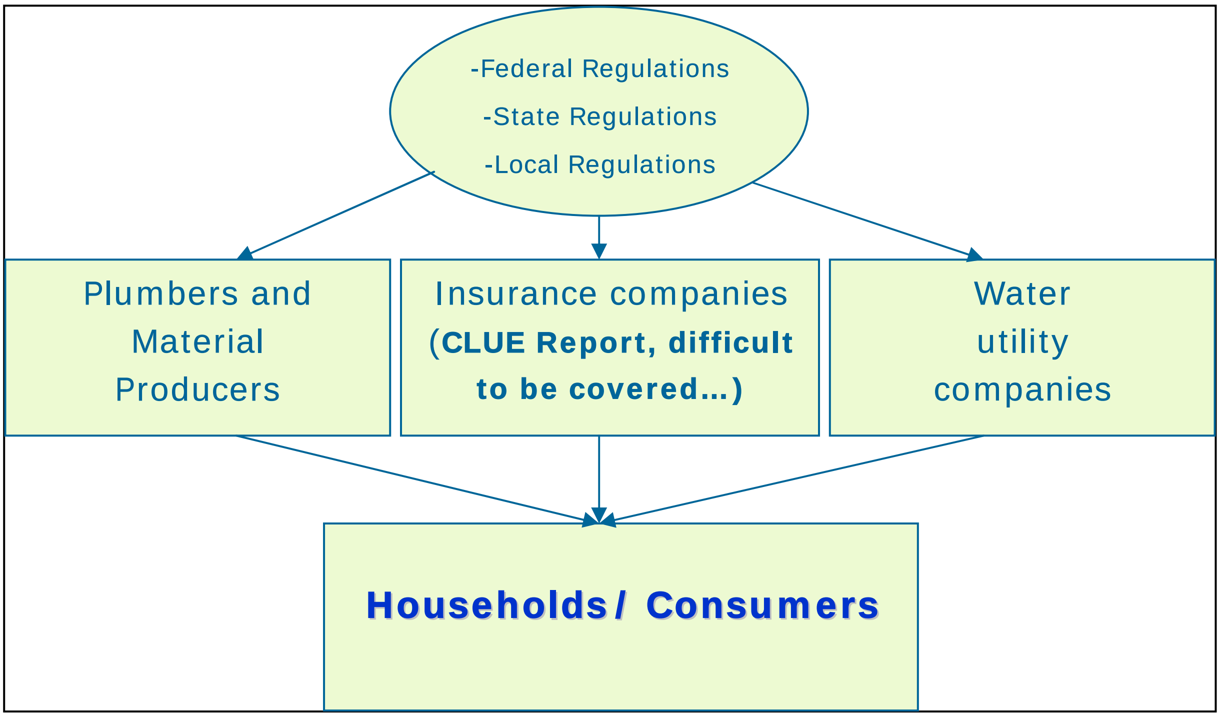

Figure 1.4 Relations on Consumer decisions

Insurance companies have access to CLUE reports (Comprehensive Loss Underwriting Report) which form a comprehensive database of personal property information relating to insurance claims on private property. It is managed by ChoicePoint Asset Co. located in Alepharetta, GA. It contains personal information on the insured, the name of the insurance company involved, the policy number, the claim number, the accident, as well as the amount paid out to the customer. Finally, it lists the customer's claim history report. If a customer calls the insurance company just for an inquiry of home plumbing issues, their call history is recorded on the CLUE report. Therefore, customers may have difficulty in purchasing home insurance (www.franscona.com/resource/jag403clue.htm).

The cost of corrosion to public infrastructure is estimated to be in billions of dollars without including loss of about 15% of treated water through leaks. Estimates are that in the USA alone 10~32% of the drinking water is lost due to corrosion at a cost of $22 billion per year. The cost related to corrosion in private drinking water infrastructure, or plumbing in residential, commercial, and school buildings, is nearly twice that of the public infrastructure

(Edwards, 2003).

A survey in 1999 revealed that copper was selected in 90% of new homes, followed by PEX at 7%, and PVC at 4%. The length of private plumbing in homes, residential facilities, schools, and commercial buildings is 10 times longer than that of the public infrastructure. Copper pipes can result in copper concentration change in drinking water significantly. World Health Organization recommends copper concentration not to exceed 2.0mg/L and USEPA established an action level of 1.3 mg/L for drinking water (Dietrich, 2003).

Regarding alternative drinking water sources, developing a well introduces its own water quality related issues and costs. Bottled water is typically expensive and does not address the issue of home use of water for bathing, cleaning, and other domestic activities. The quality of the bottled water has been brought into question regarding the source of that water and the shelf life from processing to consumption. Dual systems supplying potable and non-potable water require the maintenance of two networks and are clearly expensive. Point of use treatment alternatives require separate installation and maintenance costs. Pipe layout can influence the flow patterns that may have impact on corrosion. These alternatives have different life times, impacts and risks (Loganathan, 2002 MUSES proposal).

The public's perception of risk and reaction to hazards while hard to measure, play a fundamental role in this problem. Risk is an estimator of uncertainty defined as the probability of failure, which potentially affects consumer's well-being. Objective risks are based on relative frequencies of occurrence obtained from historical or experimental studies. Perceived or subjective risk involves personal or subjective judgment and is a function of confidence. Information should be provided on the implications of risks for consumers as individuals rather than as a group. Incorporation of consumers' preferences for water quality improvements in modeling can be performed by contingent valuation, conjoint analysis and decision analysis. Consumer risk averseness and proneness play a dominant role in developing a preference or utility function (Loganathan, Dietrich, 2002 MUSES proposal).

1.3 Objectives

The objectives of this thesis are to:

1) Develop a detailed description of life cycle assessment procedure and its application to copper plumbing pipe
2) Provide a comprehensive synthesis of aqueous corrosion in plumbing pipes.
3) Develop a decision support tool for repair/replacement of plumbing systems

The plumbing system deterioration has emerged as a critical issue for a significant number of home owners throughout the country. The home owners are looking for sound advice on plumbing system repair and replacement. The repair issue involves installing a new pipe along with an older pipe without aggravating the problem. For example, it has been pointed out, copper pipes should never be installed upstream of galvanized iron pipes as it can cause corrosion in galvanized iron pipes. Therefore in hot water recirculation systems, copper galvanized iron combination should be avoided. Protective interior coating of copper pipes and use of plastic pipes are being considered to prolong the life of a plumbing system. In this thesis, the focus is towards the replacement issue rather than the alternative methods of repairing.

1.4 Organization of the thesis

In chapter 2, a detailed description of life cycle assessment procedure is given along with details pertaining to copper pipe manufacturing. In chapter 3, a comprehensive synthesis of aqueous corrosion theory is given. Chapter 4 contains a preliminary analysis of observed plumbing pipe leak data. It is found that locations close to water treatment plant suffer the greatest number of leak incidents. It is conjectured that high pressure and relatively high concentration of chlorine might be the causal factors. The leak rates are also calculated corresponding to the various periods in which the houses were built. These leak rates display a late stage behavior and serve as the basis for model development in chapter 5. A decision support tool for finding optimal replacement time for plumbing systems is developed in chapter 5. In this chapter an optimization model that minimizes absolute deviations between theoretical and observed leak rates is given. Also a neural network model for leak rates is developed. These leak rates display age dependence. A non-homogeneous poisson process that accounts for time dependent leak rate is developed to generate leak arrival times. These leak arrival times in turn are used within an economically sustainable replacement scheme for determining the optimal replacement time. Chapter 6 summarizes key contributions of this thesis.