## A Decision-Analytic Approach to the Replacement of Gas Mains and Services

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One of the most important decisions that must be made by a gas distribution company is the decision on how to fund its replacement program for gas mains and services, especially for cast iron and bare steel mains and bare steel or copper services, but also for cathodically protected mains and services that fail corrosion testing. Over the years, the industry has seen many different approaches, mostly emphasizing cost effectiveness, i.e., reducing the most risk for the least money spent. In the fifteen years that this author has been involved in this work (not continuously, as I also do a lot of electric reliability work, which is comparable, but obviously different), other researchers and I have found that a decision-analytic approach to the problem has merit. This article will expound the approach and describe some cases of its application.

### Background and Literature

At least four of the applications of this approach have been cited in the literature:

- In 1992, I assisted PSE&G in a study of its replacement policy, and that research was amplified and expounded in an AGA paper by Bernadette Lochbaum (in the references of her paper, she cites the study we did together with PSE&G’s chief gas engineer Peter Collette, as “PSE&G, Energy Management Associates, GBU Gas Main and Service System Management Study, October, 1992”).
- In October, 1994, Pipeline Industry published a paper by me and Ken Elenbaas, chief gas engineer for Consumers Power, titled “Formal Decision Analysis Process Guides Maintenance Budgeting,” that described how we applied the approach there.
- In 1995, before the Philadelphia Gas Commission, Philadelphia Gas Works submitted testimony on their Capital Budget that included the mains and services replacement study we did with Dennis Stinson, then VP of gas engineering there.
- Finally, in July of 2005, Entergy presented a paper at the Southern Gas Association Operating Conference in Albuquerque that demonstrated how we applied the methodology to their gas properties in Louisiana.

The PSE&G work is still the basis of their policy, with many of the same graphs still used in updated form. Likewise for the Consumers Power study. The PGW work has been formally revisited and re-testified to by me in 1999, 2002, and 2004. And the Entergy work is quite recent. In addition, the approach has been used successfully at other companies without publication of the results. Also relevant is my March 2004 article in Public Utilities Fortnightly, “The Reliability Conundrum – What Is the Right and Prudent Level of Spending on Service?”, which gives many examples from electric reliability but is generic in principle and speaks to the issues that are relevant for funding of replacement programs for gas distribution companies.

## The Approach

The heart of the approach is to set the problem in a classic decision-analytic framework, in which the focus is on what decisions can be made, what random influences affect the outcomes, and how the company should value the consequences of the outcome relative to the costs of the program. Each of those elements is carefully chosen and worth exploring individually:

What decisions can be made?

One key insight is to properly understand what are the decisions that need to be made. At the simplest level, it could be described as how many feet of pipe of each type need to be replaced in a given year. But typically, a little analysis will show that the decisions are not so simple. For example, in cast iron main replacement, one is often faced with the decision of whether to replace main when the city is opening a street for sewer work or re-paving. This changes the cost and may affect the likelihood of a leak or break as the soil is disturbed and heavy equipment is rolled over the area. Also, you may find that part of the program must be to replace main under repair when it evidences significant graphitization (perhaps so much that you cannot effectively clamp it). That part of the decision is then dependent on how many such incidences you find in a year, and may be affected by the weather that year. Likewise, some decisions may be inter-related, as the decision to survey more intensively may increase the opportunities to reduce risk through either repair or replacement. Interestingly, the classic decision that is supposed to be at the heart of the problem: whether to repair or replace, is often misstated. In an emergency situation, like a major break, repair is the only safe option at the time. After the repair is made, the decision to replace that particular piece of pipe may be no more compelling than any other piece of previously broken pipe, of which there are many.

In short, one of the first things a decision-analytic approach will help you do is to focus on what real options you have, and how they relate to the uncertain influences that affect the problem.

What are the uncertain influences?

The next key insight is to understand how the uncertain influences play into the decisions and the consequences. This is typically done by starting with an influence diagram of some sort, which should be familiar from quality-circle root cause analysis and similar approaches (see the Consumer Power paper for an example). Then, that diagram is translated into a spreadsheet model that shows the impact of different decisions on the outcomes, with different scenarios or probability distributions based on the uncertainties.

For example, it is well known that frost causes breaks in cast iron main, and in a non-linear fashion (see the PSE&G paper or the PGW testimony). This means that a policy that seems fine in most years needs to be evaluated in the context of what would happen in a record-breaking year of cold, like 1987. After all, would we be satisfied if the Army Corp of Engineers built dams only for the average year’s rainfall? And don’t our gas engineers (and electric company engineers as well) plan main infrastructure projects based on a 'design day', e.g., a one-in-twenty year day for weather? Gas pipe replacement must follow the same conservative principles.

Now, there are various ways of incorporating such uncertainty into the analysis. Some readers will assume that when I recommend a decision-analytic approach I mean you should use some engine of probabilistic calculus like Crystal Ball or At Risk. In fact, I do not. Regular Excel spreadsheets can do the job nicely, provided you use them properly by evaluating them with different 'what-ifs' and well-chosen scenarios that reveal the range of risks associated with the decisions.

Also, the distribution of outcomes should include some sense of the diminishing returns associated with almost any program of this type. The biggest impact comes from doing the "worst first", i.e., replacing the pipe that has the highest risk, with an eye as well to the cost of the replacement. This is the heart of many of the programs that have been developed for pipe replacement prioritization. Some of the drawbacks in those programs are not due to capture of the diminishing returns aspects, which is valid, but to improperly framing the way the decisions interact with the influences, e.g., not recognizing economies of scale in replacing segments.

It would be repetitive to list here the influences that should be considered. Clearly, besides weather they include pipe size, type, and pressure, soil, interference, leak rates, break rates, public safety parameters (population density, etc.), operating considerations, capacity, and cost variables.

How do we value the consequences?

The final key insight is to relate the decisions and the influences to the consequences of the outcomes. This gets into the area of how to value the reduction of risk. Is eliminating a leak the same as eliminating a break? Are all leaks of the same risk? Obviously, the answer in both cases is no, and gas companies have developed many ways of classifying leaks for their degree of risk. An example of this logic can be seen in the PSE&G paper, where an "index of risk" is developed for cast iron main breaks by multiplying the break rate for different diameters and pressures by the volume of gas that would escape for each diameter and pressure.

With some companies, we have worked to develop a dollar value of the consequences. This can be done either by explicitly studying the costs of repair, damages, claims, public relations, regulatory penalties, etc., which many shy away from for obvious reasons, or by developing an index that is similarly weighted (which can be viewed as the dollar value without a dollar sign). At the very least, the value can be perceived as the marginal cost of the replacement program itself. If, for example, at the margin it costs the company $250,000 to replace a mile of cast iron main, and the main breaks at an annual rate of one every ten miles, then it costs the company $2,500,000 of this year's capital to avoid one break per year for life of the pipe. While this cannot be used to decide whether it is worthwhile to replace another mile, it can be used to evaluate all the alternative ways of reducing risk.

As to how to decide how much ultimately to replace, the three-part test described in the Public Utilities Fortnightly article can serve well:

- Historical trends in leaks and breaks – when weather-normalized, are they stable?
- Benchmarking – How do leaks/breaks and replacement compare with other utilities?
- Prediction modeling – What is projected to happen in the future under various scenarios?

A key stake in the sand is whether system integrity is getting better or getting worse. If the trends and modeling indicate that leaks and breaks are rising and will continue to rise at the current and recent historical levels of replacement, then the presumption would be that more replacement is needed. If current replacement leaves rates stable, then the next questions would be, are we satisfied with what we have, or do we need to get better? And how much will it cost us to get how much better? Is there a natural 'knee of the curve' that we can reach for, where spending stops being as effective? These are all part of the ultimate decision, and will vary by company.

From studying various companies one can come to the conclusion that for many years gas distribution companies have been able to maintain the level of leaks and breaks on cast iron and bare steel mains with a replacement program of about one percent per year. Obviously, this would imply a hundred-year replacement program for pipe that in many cases is already over 100 years old. Yet, until pipe starts breaking at a significant rate, it can seem impractical and uneconomic to replace it. Probably the typical profile is that a company will replace pipe at a rate that keeps its leaks and breaks fairly stable to slightly declining. This will probably mean a slightly increasing amount per year as pipe deteriorates, although it might stay relatively fixed for, say, five years, until a change in the trend is perceived. Once companies get the inventory of trouble-prone pipe to a small enough amount, many accelerate their programs to a ten- or twenty-year program in order to eliminate the risk entirely in the planning horizon. Again, this can be seen in the PSE&G, PGW, and Entergy papers that compare the replacement rates of different companies – the ones with the most inventory replace the smallest percent (this is not reverse causality, but a conscious choice by the companies with the most pipe).

**Conclusion**

The wisdom of taking a decision-analytic approach of the type described here has been proven by many companies. Of course, the real benefit comes in how artfully one applies such an approach to arrive at the decision that makes the most sense for the company, its customers, and its regulators.