Management of valves to improve performance reliability of distribution systems

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http://dx.doi.org/10.5942/jawwa.2012.104.0087

The overall reliability of a distribution system depends largely on valve reliability, location, and adequacy of number as well as the frequency of failure of water mains. Clearly valve management is an essential aspect of distribution system management. This article describes applications of the Strategic Valve Management Model (SVMM) to demonstrate how the computer program can be used to identify pipe segments associated with pipe breaks, determine which valves to close to isolate the breaks, and perform analyses of valve management alternatives (including present worth costs) to reduce customer service interruptions. Valve management alternatives include the addition of new valves, improvement of valve reliability by exercising valves, or a combination of the two. Simple performance indicators were developed to evaluate the performance of valve-isolating systems. This article expands on previous publications by demonstrating applications of the SVMM to hypothetical and actual water distribution systems.

Water main breaks are the primary cause of unintended outage of water in a distribution system. Nonetheless, the importance of valves in isolating breaks and minimizing the number of customers out of water has not been given sufficient attention. To date, few if any standardized tools are available for water utilities to evaluate and to develop a valve management program.

This article, based on a Water Research Foundation study (Deb et al, 2006) discusses application and use of the SVMM model. It also analyzes capital and operations and maintenance costs of valves under alternative valving strategies to develop an optimized valve management program for a water system. The tools developed in this study can help water utilities evaluate their existing valve systems and increase system reliability through the addition of new valves and improved valve reliability.

Walski (1993) first recognized the importance of valves. He defined a segment as the portion of the network that can be isolated by closing valves. Findings from a workshop on criteria for operating and maintaining valves (AwwaRF–Kiwa, 2001) concluded that strategic valving is a balancing act between managing failure probability and managing consequences of failure. Utilities were advised to improve valve reliability by implementing an intensive valve-exercising program and using additional valves.

PERFORMANCE INDICATORS

When a water main breaks, the broken pipe is isolated, and the outage can be managed by closing a set of valves. In the planning mode, the optimal locations for valves are determined to provide maximum control within budgetary restrictions. An existing system of valves may also be enhanced by additional valves and improved valve reliability.

Customers in the isolated system will experience a water outage, and this system of pipes is termed a segment. Ideally, segments should be as small as possible in order to minimize the number of customers affected. Performance indicators were developed to help ensure that these values are within norms of a good valving system and to assess performance of existing valving systems. Some of the performance indicators—such as the ratios of pipe length to valve and number of customers to valves—are simple and easily developed. The SVMM can be used to develop more complex performance indicators, such as average length of a segment, average reliability of isolating a segment, and average number of valves to be closed to isolate a pipe break.

Another performance indicator, the valve importance index (VII), shows the effect of valve failure in terms of additional customers without service. It can also be expressed as a percentage of customers who will be out of service if a specific valve fails to operate effectively. When a valve fails, additional valves must be closed to isolate a break, resulting in additional customers being out of service. The number of additional customers out of service because of valve failure is termed the VII of that valve.

The average reliability of isolating a segment is the product of the reliabilities of all valves required to isolate that segment. For example, if four valves are required to isolate a segment and the reliability of each valve is 0.9, the reliability of isolating a segment = 0.9^4 or 0.66. For a pipe consisting of two valves at the end, the reliability of isolating the segment = 0.9^2 or 0.81.

SVMM ANALYSES

In the current study, the SVMM was used to analyze a hypothetical distribution system and an actual distribu-
tion system. The model was used to perform delineation of segments and conduct deterministic (tier 1) and probabilistic (tiers 2 and 3) analyses.

The purpose of tier 1 deterministic analysis is to determine systemwide performance indicators, identify pipe segments, and define and determine VIIIs for all valves. Tier 1 analysis is based on the distribution pipe network configuration and valve locations, and all valves are assumed to have 100% reliability.

In tier 2 and tier 3 analyses, a probabilistic framework is used by eliminating the assumption that all valves operate properly at all times. In tier 2 analysis, the effects of a single pipe break on a customer outage are examined by sequentially allowing each pipe to fail, one at a time. In tier 3 analysis, the entire system is examined in a probabilistic framework using Monte Carlo analysis methods.

**MODELING OF THE HYPOTHETICAL NETWORK**

The hypothetical network used in this study was based on a realistic water distribution system. The service area is primarily residential and covers approximately 2 sq mi (5 km²), with an average water use of approximately 0.5 mgd (1,700 m³/d). The hypothetical network comprises 90 nodes, 104 pipes, 94 valves, 1 storage tank, and a source reservoir that represents the pump station providing water to the system. The system serves an estimated 2,335 equivalent residential customers.

Results of the hypothetical network analysis indicated that average pipe length per valve is 725 ft and the average length of a segment is 960 ft. The average number of valves required to isolate a pipe break is 2.45, and on average, 210 customers will be out of water if a valve fails. Analysis also found that four valves have the highest VII value of about 38%, and the average number of customers affected almost triples when the average valve reliability drops from 90 to 50%.

**Methodology.** There are two basic approaches to improving distribution system performance: increase the reliability of the existing valves by improving the valve exercising program or increase the number of valves in the system. It is possible to reach the same reliability goals using a combination of the two strategies. The SVMM was applied to the hypothetical test case to evaluate existing valve configuration and five additional scenarios: one valve per pipe, one valve per pipe and one valve per node, the \( n - 1 \) rule (i.e., one valve fewer than the number of pipes at a junction), the \( n \) rule (i.e., an ideal fully valved system with two valves for each pipe located at its ends), and addition of six valves to reduce large segments.

The results showed that average customer outages could be significantly reduced by adding valves in the system. Combinations of improved valve reliability and valve addition can be used to achieve a target service level.

**Cost analysis.** Cost data on valve replacement and maintenance were collected from various utilities and a valve-maintenance outsourcing company. These data were used to develop the present worth cost and an annualized cost for improving the performance of a valving system by adding new valves and improving valve reliability.

The SVMM developed customer outage versus valve reliability curves to determine the most cost-effective option to limit maximum customer outage. These curves and cost data were then used to analyze combinations of additional valves and increased valve reliabilities to obtain a least-cost solution. The costs of each combination were also determined. The least-cost option to achieve the desired goal is generally to increase valve reliability by intensifying the valve-exercise program. The study also developed a simplified methodology for small utilities to analyze alternative valve management plans.

**CONCLUSION AND RECOMMENDATIONS**

Study results led to the following conclusions and recommendations:

- The SVMM model applied in the hypothetical and test case studies demonstrated that the model helps water utilities prioritize valve operation and maintenance programs.
- When SVMM software is not available, the simplified methodology with limited data may be used cautiously to develop a cost-effective valve management program.
- The option of improving the valve-exercising program to increase reliability was determined to be more cost-effective than addition of new valves.
- To facilitate the use of SVMM software, utilities should collect and maintain valve data in a computerized database linked with the utility’s geographic information system database.

Based on the authors’ experience and analyses performed in this study, the following rules for valve placement and maintenance practices are recommended:

- For proper valving of a distribution system, a utility’s goal should be to have enough valves to satisfy the \( n - 1 \) rule (i.e., \( n - 1 \) valves at a junction of \( n \) pipes).
- Average pipe length per valve should be between 500 and 700 ft.
- Maximum distance between valves in a distribution system should be 500 to 800 ft.
- Maximum number of valves to be closed to isolate a break should preferably be four or fewer.

**REFERENCES**


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