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Key Criteria for Valve Operation and Maintenance

AwwaRF-Kiwa workshop, Nieuwegein,
March 29-30, 2001

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Preface

On March 29 and 30, 2001 the AwwaRF-Kiwa Valves workshop was held. Valve experts from 10 countries and 5 continents gathered at the offices of Kiwa Water Research in Nieuwegein, The Netherlands to discuss operation and maintenance of valves. Ignited by two short presentations the workshop participants entered an open and lively debate on valve reliability, location criteria, maintenance programs, valve exercising, etc.

Valves constitute a critical component in the reliable operation of a utility's distribution system, especially in minimising service interruptions and ancillary damage during emergencies. Objective of the workshop was to gather information and experience on valve operation and maintenance from around the world in order to outline best practices.

Based on the reactions and comments of the workshop participants it is felt that the workshop yielded useful and practical results as well as questions that need further attention.
AwwaRF and Kiwa will use the results of the workshop to outline further research on valves operation and maintenance.

Kiwa Water Research – workshop host and primary investigator for this joint AwwaRF-Kiwa project – and AwwaRF wish to thank all workshop participants for their support and contribution before, during and after the workshop. Further thanks go to all respondents to the questionnaire for sharing their valuable and much appreciated information.

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Summary

Valves constitute a critical component in the reliable operation of a utility's distribution system, especially in minimising service interruptions and ancillary damage during emergencies. Objective of the valves workshop was to gather information and experience on valve operation and maintenance from around the world in order to outline best practices.

A literature review and a questionnaire were done to prepare the workshop. The results were discussed and translated into valve project sheets. Important findings were:

- Valve selection is crucial for future performance. Compared to overall maintenance costs associated with a valve over its life, the initial purchase cost may not be very significant.
- Worldwide there are very few absolute rules on the location of valves. As a result of this there is also little information on the associated risk level.
- Valve reliability in itself is not the issue: isolation reliability is.
- In any system there are valves whose failure can lead to failure of a important part of the system or even the whole system. These crucial valves deserve special attention.
- The key perfomance criterion for a valve is valve reliability. Valve reliability can be defined in terms of being able to find, access, operate and open or close the valve. Exact definitions could not be found.
- Very little information was found on the actual reliability of valves.

From the project sheets, some basic recommendations can be derived on valve operation and maintenance and specifically on answering the questions that are still open and the items that need further attention in research. Recommendations of the separate Kiwa report on "Requirements for valves from a customer's point of view" (BTO 2001.156 (s)) have also been included.

Valve location

- Use clear and uniform section criteria based on an analysis of failure probability, valve reliability and failure consequences.

Valve operation and maintenance

- Provide clear and uniform operation and maintenance procedures. These should include the gathering of information on the status and condition of the valve.
- Document information on actual valve reliability and on consequences of unreliable valves.
- Provide clear and uniform procedures for valve operation, inspection and exercising. Register and analyse the data to find trends and to establish inspection intervals (see future research).
- Incorporate pragmatic operational tools in network information systems to facilitate quick section analysis. This can be extremely helpful in case of an emergency.

Future research

- Put valves higher on the research agenda. Despite their presence in high numbers and their important role in the distribution system, little is known about their performance, their reliability and the consequences when they fail.
- Define and assess valve function reliability. In order to do this research should concentrate on reliability of single valves, valve location and establishing reasonable reliability criteria.
- Establish inspection, exercising and operation frequency based on a return-on-investment analysis. Research should focus on providing key figures for inspection, exercising and operation, as well as the return in terms of system reliability improvement and other benefits.
- Determine how factors such as age, water quality, soil conditions, hydraulics, etc. influence the reliability of valves in order to predict valve condition and establish inspection, exercising and operation intervals.
- Develop an easy-to-use tool for reliability analysis for complicated networks. It will be a challenge to find or develop a mathematical rule for calculation of system reliability in order to make automatic calculations possible.
- Develop a strategic 'valving' tool for assessment of system security investments. The tool should be able to assess best investment policy by balancing between investments in limiting pipe failures, smaller sections, more reliable valves (valve selection, intensive valve control program) and damage control.

Contents

1 Introduction

Valves constitute a critical component in the reliable operation of a utility's transmission and distribution system, specifically in minimising service interruptions and ancillary damage during maintenance activities and in case of pipe breaks or other emergencies. On the actual reliability of valves and best practices on operation and maintenance of valves little information was available. This was the reason to place valves high on the research agenda of both AwwaRF and Kiwa Water Research, which resulted in the workshop to develop "Key Valve Operation & Maintenance Criteria". The "Valve workshop" was jointly funded through the AwwaRF research program and the joint research program of the Dutch water companies. Kiwa Water Research was the principal investigator.

On March 29 and 30, 2001 the AwwaRF-Kiwa Valves workshop was held. Valve experts of 10 countries and 5 continents gathered at the offices of Kiwa Water Research in Nieuwegein, The Netherlands to discuss operation and maintenance of valves. The objective was to develop key valve operation and maintenance criteria by gathering information, experience and best practices on valves from around the world.

Workshop program and participants are presented in Appendices I and II.

Prior to the workshop a literature review was done and a questionnaire was prepared and distributed among water utilities, valve experts and valve manufacturers around the world. The results of the literature review are presented in chapter 2. Chapter 3 discusses the primary findings of the valve questionnaire.

The results of the literature review and the questionnaire were used to stimulate discussion on operation and maintenance of valves. The major valve topics were prioritised and discussed in small groups. The discussion results were reported in valve project sheets. These project sheets are presented in chapter 4.

From the project sheets, some basic recommendations can be derived on valve operation and maintenance and specifically on answering the questions that are still open and the items that need further attention in research. Chapter 5 gives a summary of these recommendations.

2 Valve literature review

2.1 Introduction and focus

In the preparation of the valve workshop a literature review was done. Information sources included the Internet and water databases of the Water Research Centre in the UK (Aqualine abstracts), AWWA in the US (Waternet), AwwaRF in the US and Kiwa in the Netherlands. The valve questionnaire that was done in the course of preparing the workshop also yielded some valuable literature suggestions.
The primary focus of the workshop and the literature review was on operation and maintenance of shut-off valves: valves that are used for isolation purposes and redirection of flows. These valves constitute the majority of valves in a regular water supply system.
The results of the literature review are grouped as follows:
- Design and installation;
- Performance;
- Operation and maintenance: programs, guidelines and tools.

To provide key criteria for valve operation and maintenance (O&M) it is important to define valve performance since O&M activities are aimed at ensuring that valves work properly. Design and installation strongly influence both performance criteria and actual performance and should be the starting point of any discussion on O&M criteria.

2.2 Design and installation

2.2.1 Valve function

The primary purpose of valves in distribution water mains is sector isolation [Hoff, 1996]. Sector isolation is necessary to repair main breaks or to carry out specific maintenance activities or extension works. Redirection of water flows for pipe cleaning purposes or emergency water supply is another function.
For these purposes shut-off valves are selected. Typical shut-off valves encountered in literature are wedge gate valves, double disc gate valves, resilient seated gate valves and butterfly valves.
Other functions for which specific valves are used are control of flow and pressure, reverse flow prevention and overpressure protection.

2.2.2 Valve selection

Literature stresses the importance of selecting the proper valves for the proper purposes. Manufacturer Bopp & Reuther states that up to 80% of all valve failures are caused by wrong selection of valves [Kipping, 2001]. This information is based on estimations of experts. A substantiation of this

estimate cannot be made because very little can be found in literature on actual failure data.
With valve selection being crucial for future performance it is considered wise to include long term considerations when specifying valves. According to Hoff these include own experience with the performance of the valves and the service, training, technical competencies and assistance, quality, reliability, and reputation of each manufacturer.
Basic information on valve selection criteria and specifications can be obtained from valve manufacturers. Comprehensive information on valve types and specifications, and selection criteria can be found in the Valve Handbook [Skousen, 1997]. The Handbook also states that compared to overall maintenance costs associated with a valve over its life, the initial purchase cost may not be very significant.

2.2.3 *Storage and installation*

If valves are not stored and installed according to the manufacturer's specifications a negative impact on valve performance is likely. Hoff presents some general storage and installation recommendations to ensure optimal performance:
- prevent prolonged exposure of rubber compounds and seals to UV (sunlight);
- prevent accumulation of dirt;
- inspect the valve prior to installation, the valve should be clean and undamaged;
- test the performance (open/close);
- install valve in the closed position;
- align pipes properly before valve installation;
- ensure a proper water main foundation.

2.2.4 *Valve location*

Valve location depends largely on the utilities' criteria for sectioning. Larger sections mean fewer valves. Failure consequences are more serious however. Worldwide there are very few absolute rules on the location of valves:

US [Walski, 1993 and personal correspondence]:
- AWWA Water Distribution Manual (1986): less than 500 ft (150 m) apart in business districts and less than 800 ft (240 m) in other parts;
- AWWA M-31 Fire protection manual: not more than 500 ft (150 m) apart in "high value districts" and not more than 800 ft (240 m) "on long branches" as typical values;
- usual practice: at least two valves at every T-type intersection and three at each cross-type intersection;
- rule-of-thumb: operation of no more than four valves for segment isolation.

Japan [JWWA]:
Water conveyance pipelines:
- Valves at start and end points;
- Valves at both ends of special constructions like water pipe bridges;
- Valves at 1 to 3 km intervals;
- Drainage facility between valves;

Distribution mains:
- Valves at the starting point of each distribution main, branch points, crosses, both ends of water pipe bridges;
- Valves at 1 to 3 km intervals;
- Valves at top and bottom of long slopes and large height differences.

As there is little information on location criteria there is also little information on the associated risk level. Risk is calculated as the product of probability of failure and consequence of failure:
- Failure probability:
  General pipe failure statistics are usually available on a basic level but often there is little information on specific failure statistics, related to pipe location, pipe material, age, etc.
  Although valve control and exercising programs are mentioned often in literature, the results of these programs are seldom published. This means there is very little information on valve reliability.
- Failure consequence:
  What goes for failure statistics also goes for the consequences of failure: very little is published. There may be a reluctance to do so, because of the negative public impact. Usually only the serious failures are well documented because of the headlines and the demands for thorough investigation they create.

The influence of valve location as a design criterion on system reliability has been studied by Bouchard and Goulter [1991] and by Walski [1993]. The influence of valves on system reliability is obvious if one would consider a system without any valves. As Walski put it this system would be crippled during every pipe break or maintenance event requiring a shutdown.

Systems may look reliable when viewed on a map, but lack of valves or wrong location of valves can demonstrate otherwise. Because of the historical growth of systems and interconnections many systems are quite complex and insight in the reliability of the system may be difficult to obtain.
Walski introduced a specific valve topology to facilitate reliability analysis with regard to valve location: the segment diagram. Walski defined a distribution system segment as the smallest part of the distribution system that can be isolated by the closing of valves. To prevent confusion with other parts of this report the word 'section' is used where Walski uses 'segment'. The segment diagram – or section diagram – is a conversion of a regular distribution map. The conversion comes down to representing the sections as nodes and the valves that separate sections as lines (figure 2.1).

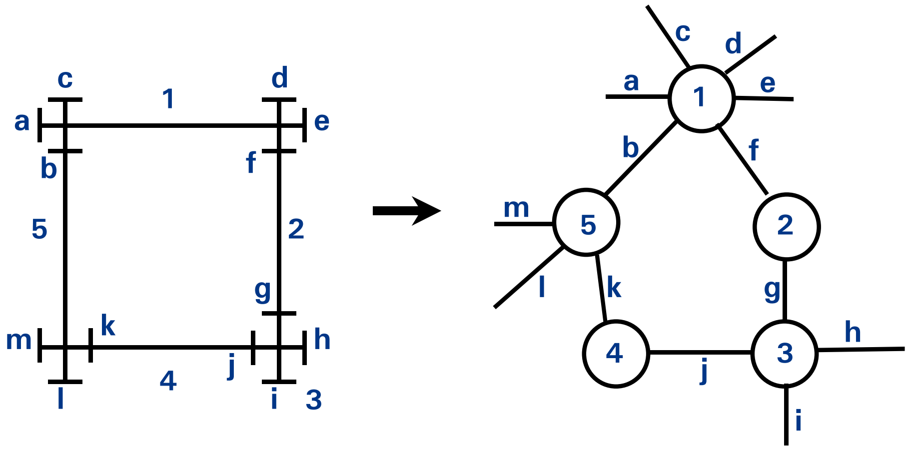


Figure 2.1. Converting a distribution map into a section diagram (Walski)

From the example in figure 2.1 can be seen that for isolation of section 2 only two valves (f,g) need to be operated, whereas for isolation of section 1 six valves (a to f) are needed.

This demonstrates that valve reliability in itself is not the issue, but isolation reliability. Walski convincingly shows that valve reliability and isolation reliability is not the same. For example:

- when the reliability of any valve in the system is 0.9 (90%), and
- when four valves are needed to isolate the section,
- then the reliability for isolation of that section is $0.9^4 = 0.66$ (66%).

The section diagram can be used to assess the reliability of isolating a section, provided valve reliability is known. It will also help to assess what happens when a valve fails. If for example section 5 from figure X has to be isolated because of a pipe break and valve k fails then only valve j should be closed, isolating section 4 as well. Should valve b fail however, then closing valves a, c, d, e and f should be attempted and section 1 will be isolated.

2.3 Performance

2.3.1 *Valve reliability*

As for performance criteria, essentially only one criterion is important: valve reliability. To be able to use valve reliability as a criterion it has to be defined. Various literature sources define a reliable valve as one that:
- can be found and identified in all weather conditions (maps, identification shields, etc.);
- is accessible (no obstacles on cover, not paved over);
- can be operated (no broken or bent stem or rounded operating nut, no obstructed or jammed valve);
- works properly (watertight shutdown, no packing leaks).

Exact definitions could not be found. For example: Does a watertight shutdown mean a 100% watertight shutdown or can a certain amount of leakage across a valve be accepted?

Very little information was found in literature on the reliability of valves. Although many publications mention valve operation and maintenance programs the results of these programs are seldom published.
The Boston Water and Sewer Commission [Shea, 1991] published their experiences with a maintenance program for their 17,000 in-line water valves in the Boston system. Some of their results were:
- about 10% of the valves needed frame and cover adjustments;
- initially 120 out of 2,800 valves could not be operated;
- 105 out of these 120 valves could be cracked after setting a less conservative upper limit on torque restrictors;
- large number of valves with packing leaks, attributed to prolonged shutdown of valves;
- resilient seated gate valves (used since 1988) presented no problems.

2.3.2 *Other performance indicators*

Costs
Naturally costs are mentioned often as a performance indicator. Much emphasis is placed on life cycle costing. As mentioned before the Valve Handbook [Skousen, 1997] states that compared to overall maintenance costs associated with a valve over its life, the initial purchase cost may not be very significant. These overall maintenance costs are determined by:
- frequency and characteristics of maintenance (planned or emergency, accessibility, ease of maintenance, labour requirements, special tools, etc.);
- costs of spare parts;
- costs associated with service interruptions, water loss, water damage, etc.

Exact life cycle costs associated with valves could not be found in literature.

Torque needed for operation
The amount of torque needed to operate a valve can be an indication for the need for maintenance. Corrosion or dirt can hamper the operation of a valve, making it less easy to operate. Regular torque measurements can provide information on the speed of this process. Results should be interpreted in relation to the valve specifications.

Noise level
Increased noise levels over valves may indicate a problem such as partially closed valves. This may lead to cavitation. Acoustic measurements are used to assess whether or not a valve is fully closed. Interpretation of results can be difficult, especially when other sources of noise are present.

2.4 Operation and maintenance: programs, guidelines and tools

2.4.1 Introduction

Throughout literature many examples of best practices, procedures, guidelines, tips&tricks and tools on valve O&M can be found. This paragraph presents a summary.

2.4.2 O&M procedures

Valve manuals
Valve manufacturers will provide manuals with their valves. Naturally, these manuals are an invaluable source of information for O&M procedures. They are to be followed to prolong the service life of a valve and to prove rights to warranty if necessary.

Company policy
Maintenance programs are usually dictated by company policy. In these programs maintenance procedures, maintenance frequency, performance criteria and evaluation procedures are described.
Smit [2000] describes a TQM-approach following the Plan-Do-Check-Act-cycle:

- Plan
  - Carry out a functionality test every 6 years
  - Carry out an availability test every 2 years in cities and every 6 years in rural areas
  - Setting policy goals for reliability, costs, complaints, etc.
- Do
  - testing, checking and registration using a Mobile Data System (MDS)
- Check
  - Data analysis:
    - Actual reliability versus reliability goals
    - Actual time and costs versus time and cost prognosis
    - Actual complaints versus complaint prognosis
- Act/Adjust
  - If necessary: adjustment of maintenance program based on the ‘check’-results

The Japan Waterworks Association [JWWA, 1987] follows a similar approach in their Valve Handbook for Waterworks. JWWA states that it is necessary to inspect and service valves according to their purpose and importance. Excessive maintenance should be prevented. Each organisation should determine the maintenance frequency and procedures based on the importance of the valves and previous experience.

2.4.3 *Failure analysis*

JWWA stresses the importance of failure analysis with respect to determining maintenance frequency and procedures. Diagnosis of malfunctioning valves is aimed at finding the causes of the problems and the possible solutions to solving or diminishing them so that the lives of other valves can be prolonged. This will also help to further focus the valve maintenance program.

Typical failure analysis includes:
- evaluation of design and location
- evaluation of valve selection
- evaluation of storage and installation
- analysis of past operation
- analysis of past problems
- analysis of valve condition (rubber degradation, corrosion, damage)
- analysis of the role of water quality, soil condition, internal and external load, etc.

Naturally these data should be registered and available for future analysis.

2.4.4 *Data registration*

Analysis of failures and evaluation of maintenance programs requires registration of data. Data registration should be beneficial and careful thought should be given to a balanced registration. Most database systems for these purposes are GIS-based. Mobile data systems are available and are often included in valve keys for torque and noise measurements in order to directly process the data.

Recently also valve based data registration is available. There are programmable valves, where PLC is integrated in a valve capable of function monitoring [Kellerman, 1998] and 'intelligent' valve keys with read/write data capsules embedded in the valve head [Whittaker, Arscott, 1997].

2.4.5 *Operational problems and solutions*

Literature provides ample descriptions of common valve problems and solutions. From publications by Shea and Hoff table 2.1 was derived.

Table 2.1. Common valve problems and solutions

Valve problem	Solution
Buried valve cover	Raising casting
Temporary buried cover (snow, ice)	Accurate location records, identification
Inaccessible (cars, trees)	Relocation, accessibility measures
Unidentifiable valve	Valve identification
Access tube filled with debris, dirt	Cleaning
Operating nut rounded	Nut replacement
Valve stuck	Exercising valves, remove obstruction
Broken stem	Replacement
No watertight shutdown	Exercising valves
Packing leaks	Repacking
Vibrations, noise	Adjust valve opening to prevent cavitation
Discoloured water	Pipe cleaning, public relations
Problems caused by external contractors	Training, education, checking
Partially opened valves	Control program
Illegal valve operation	Control program

2.4.6 *Preventing problems*

The Japan Waterworks Association (JWWA) presents an overview of do's and don'ts to prevent problems with valves:

- do not touch the stroke limit switch and torque limit switch of powered equipment unless necessary;
- always check opening/closing direction before valve operation;
- manual operation: do not turn the handle to the fully closed or open position with any more force than necessary;
- if the electric motor stops during operation or manual operation suddenly becomes heavy, do not use force to try to operate the valve;
- do not perform powered operation during manual operation;
- do not use valves at a partially opened position because of cavitation risk;
- refrain from opening or closing valves rapidly;
- be particularly careful with valve operation when valves are fully opened or closed;
- after fully closing a valve, check that the water has been cut off (visual, noise, pressure).

3 Valve questionnaire

3.1 General

Before the workshop a questionnaire was sent to the participants and several manufacturers. The results of the questionnaire give some general insight in present operation and maintenance of valves. These results were presented at the beginning of the workshop. The figures and percentages in this report are based solely on the information from the questionnaires received. The response to the questionnaires was high. Initially 16 out of 18 utilities responded, 9 out of 18 specialists and 4 out of 5 manufacturers. After the deadline another 3 utilities and 2 specialists responded. Information of these questionnaires was used in a qualitative sense.
The 16 utilities represent 111,570 kilometres of pipeline, 6.175 billion cubic meters of water supply annually and 897,471 valves.
Questionnaire respondents are presented in Appendix III.

3.2 Valve type and valve function

More than 99% of all valves have an on-off function. Less than 1% is used as throttle or non-return valve. Only 1% of all valves are automated.

The dominant valve type is the gate valve (figure 3.1).

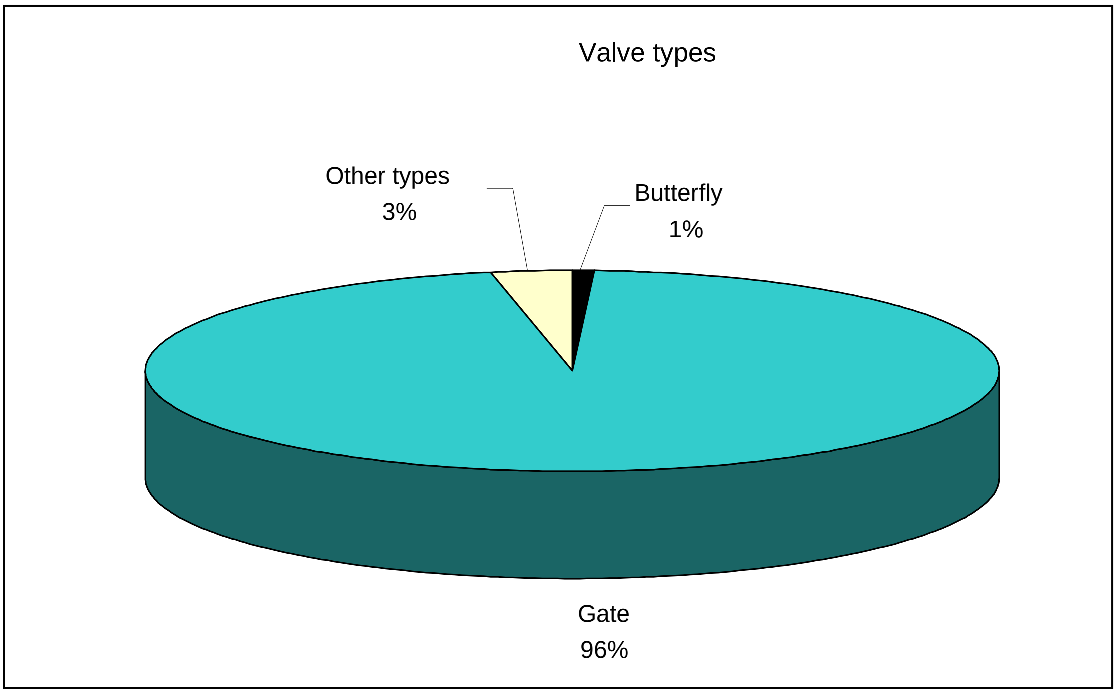


Figure 3.1. Valve types

In figure 3.2 valve classification to distributive functions is shown.

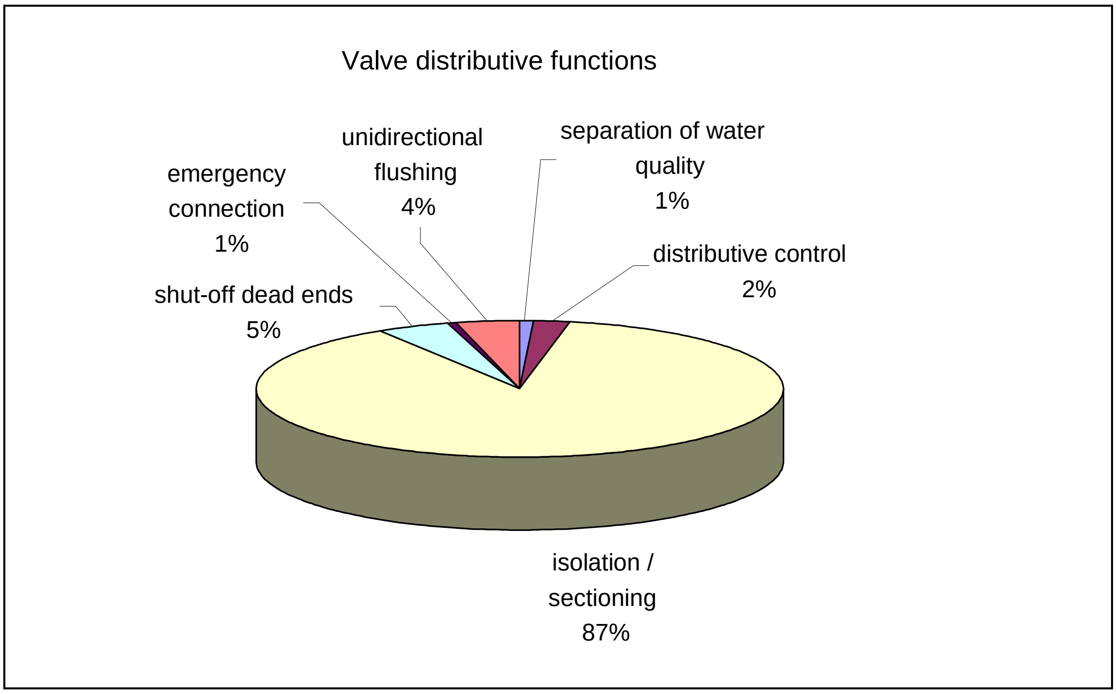


Figure 3.2. Valve classification to distributive functions

From the figures about valve function, valve automation and the classification to valve type and distributive functions of valves can be concluded that more than 85% of all valves is a manual on/off gate valve.

3.3 Purchase criteria

The water utilities questionnaire asked to name and grade purchase criteria. The following grades for purchase criteria are given on a scale from 1 (not important) to 10 (very important):

Purchase criteria	average grade given (between 1 – 10)
– Reliability	9,5
– Permissible leakage	8,7
– Service	8,2
– Pressure drop	7,7
– Costs	7,5
– Operation	7,3
– Maintenance	7,0
– Service life	7,0
– Installation	6,2

Not surprisingly, reliability ranked highest on the list of purchase criteria.

3.4 Valve location

Valve location depends on the sectioning criteria. 69% of utility respondents indicated that maximum section length is a criterion. 44% use maximum number of connections as a section criterion. The maximum number of connections within a section varies from 10 to 120, with an average of 52.

The utility respondents indicated maximum section lengths between 0.3 and 5.0 km. The average maximum section length for these utilities is 1.7 km.

Based on the information of the respondents 3.7 valves per kilometre are used for sectioning (based on information of 11 utilities). This comes down to one valve per 270 meters.

3.5 Valve operation and maintenance

75% of all responding utilities carry out preventive maintenance. 63% have a testing program. The utilities using a testing program test 10% of their total valve population every year. There are large differences between utilities. Testing intensity per utility varies between 0.09% and 100% of the valve population per year.

The following items are tested / checked:
- Corrosion;
- Broken stems;
- Sticking;
- Dropped disks;
- Packing leaks;
- Lack of maintenance.

3.6 Valve reliability

Respondents valued the accessibility of their valves as follows:

<u>Valve accessibility:</u>

- Good:	83 %
- Moderate:	13 %
- Bad:	4 %

Respondents reported 0.22% valves failing to meet the testing requirements. This percentage varies from 0% to 4.75%.

The following suggestions for improvement of valve reliability were made:
- Maintenance
  - Use effective maintenance programs
  - Use a special maintenance program for geared valves and dividing valves

- Operation
  - Improve training
  - Define maximum velocities (for butterfly valves)
- Design
  - Pay more attention to valve location
  - Improve large gate valves, in order to prevent leakage into the operator mechanism and thus avoid corrosion

The consequences of valve failure may vary considerably. Increased costs are mentioned as a consequence in 98% of valve failures. The most important consequences are:

– increased costs	in 98% of all valve failures
– labour requirements	85%
– lost water	44%
– water quality problems	42%
– property damage	38%
– pressure problems	28%

The causes for breakdown of gate valves are:

– packing leaks	65%
– broken stems	14%
– sticking	6%
– lack of maintenance	5%
– dropped disk	4%
– corrosion	3%
– replaced bodies, stems, caps	3%

3.7 Valve costs

The costs (in US$) for valves consist of the following components:

Average valve costs	(US$ / km year)
– Operation	76
– testing	56
– maintenance	41
– replacement	44
– installation	49
total (US$)	262

The total costs vary between US$ 36 and US$ 620 per km a year. With an average number of valves of 3.7 per km the total costs would be US$ 71 per valve per year.

4 Workshop results: Valve project sheets

4.1 General

Results of the literature survey and the questionnaire were used as the basis for the workshop discussions. The major topics were prioritised. This resulted in a shortlist of thirteen high priority items of which seven were selected for further discussion in small groups. The discussion results were reported in valve project sheets. After the workshop draft project sheets were distributed among the workshop participants for final comments. The project sheets were edited based on the comments and are presented in this chapter.

Below the thirteen valve topics are summarised.

Valve topic	Project sheet	Comment
Operating procedures	Yes	See paragraph 4.2
Section criteria	Yes	See paragraph 4.3 and report on “Requirements for valves from a customer’s point of view”
How to prove valve function reliability?	Yes	See paragraph 4.4
Maintenance versus operation	Yes	See paragraph 4.5 and Appendix IV
Requirements for maintenance program	No	Covered in ‘Maintenance vs. operation’
What to register?	No	Covered in ‘Maintenance vs. operation’
Can there be maintenance or only operation?	No	See paragraph 4.6
Valves and fire protection	No	See paragraph 4.6
Standards: International vs. national	No	See paragraph 4.6
Distributive valves	No	See paragraph 4.6
Define the function of a valve in the system	No	See paragraph 4.6 and report on “Requirements for valves from a customer’s point of view”
Type of valve: function and reliability	No	See paragraph 4.6
Only on/off valves or also selfacting, pressure release, non return?	No	Only on/off valves. Other valves are beyond the scope of the workshop. See also paragraph 4.6: distributive valves.

During the workshop the group discussing the topic ‘Define the function of a valve in the system’ redirected the discussion towards the placement of valves with regard to system reliability. The results of this discussion are presented in a separate Kiwa report on “Requirements for valves from a customer’s point of view” (BTO 2001.156 (s)). This report also discusses section criteria.

4.2 Operating procedures (project sheet)

AWWARF-Kiwa workshop on Operation and Maintenance of Valves

Topic:

Operating procedures

Description/symptoms:
In the operation of valves there is a need for operation procedures. With such a procedure it becomes not only easier to operate the valves but it will also give you the right information about the condition of the valve.
Operation procedures will be dependent on function, size, type and place of the valve. In these procedures also the gathering of information of the valve has to be taken into account by means of a valve report to be filled.

Possible causes (in order of probability):
Not applicable.

(Directions of) solutions:

PREPARATIONS

1. INTERNAL NOTIFICATIONS:
   Notify the central operations staff 1-2 days prior to the valve operation so they are aware of any major changes in flow and pressure. Notify the central customer service staff about 1 week in advance regarding why the valve is being operated, how long customers may be affected, and how many customers will be affected.
2. EXTERNAL NOTIFICATIONS:
   Notify outside agencies (if necessary) such as fire brigade, police, road department, county, and other utilities about 1 week in advance.
3. Obtain all necessary tools and valve reports.
4. Obtain and review all relevant valve location and history data.

VALVE OPERATION

1. Always check opening/closing direction before valve operation.
2. Disable electric motor when applicable; do not perform powered operation during manual operation.
3. Determine last time of operation. If the valve has been operated within planned frequency, proceed to Step 5. If valve has been operated less frequently than planned, proceed to Step 4.
4. A valve that has not been operated for a number of years needs to be closed by using a series of up and down motions. Crews attempting to close a difficult valve should never use a T-handle and cheaterbar to force the valve closed. Such overtorquing to obtain a positive shutoff can cause damage to the valve. Torque-limiting devices are available. Crews should follow these guidelines to close a valve properly:

a. Begin with a steady amount of torque in the direction necessary to close the valve, moving trough 5 to 10 rotations.
b. Reverse for two or three rotations.
c. Reverse again and rotate 5 tot 10 more turns in the closing direction.
d. Repeat this procedure until full closure is attained.
e. Once the valve is fully closed, it should be opened a few turns so that high-velocity water flowing under the gates can move the remainder of the sediment downstream with more force and clear the bottom part of the valve body for seating.
f. Fully close the valve again.

The reason for this cautious approach is that debris and sediment often build up on the gates, stem and slides. If this material is compacted while the valve is being closed, the torque required to close the valve continues to build as the material is loaded. If the procedure described above is used, the stem and other parts are "scrubbed" by the series of back and forth motions and water in the system can flush the debris that has broken away from the stem ate and slides or guides.

5. Close valve slowly, with speed of closure based on type of valve and on manufacturer's recommendation. Closure speed should consider possible waterhammer as a consequence of closing the valve too rapidly.
6. Use normal valve operating key; do not use extension bars to increase the normal operating torque.
7. Do not exceed the normal number of turns to close the valve.
8. Be particularly careful with valve operation when valves are fully opened or closed.
9. After fully closing valve, check that the water has been cut off (visual, noise, pressure).
10. Open valve slowly: make sure valve is returned to fully open position based on the number of turns required.
11. Use normal valve operating key; do not use extension bars to increase normal operating torque.
12. Do not exceed the number of turns to open the valve.

DATA REPORTING

1. Complete valve report indicating any abnormal operating conditions and noting any need for maintenance.

4.3 Section criteria (project sheet)

AWWARF-Kiwa workshop on Operation and Maintenance of Valves
Topic: Section criteria
Description/symptoms: The problem is a lack of absolute rules on section criteria. A section is the smallest part of a network that can be isolated by properly functioning valves. For appropriate rule definition two questions have to be taken into account: - What is the probability of valve failure? - What are the consequences of valve failure? If we look at predominantly open 'small' isolation valves we can say that the consequences of valve failure can be quantified as the number of customers without water. About the probability of valve failure we can say that the higher the reliability of the individual valves and the less valves we need to isolate a section, the lower the probability of system failure will be. The lack of absolute rules on section criteria is not a desirable situation. Both the water company itself and its stakeholders demand that system reliability can be assessed and demonstrated. Without section criteria this is impossible.
Possible causes (in order of probability): Possible causes for the lack of absolute rules on section criteria are: - Little documented information on actual valve failure probability and on consequences of valve failure; - Valves have been low on the agenda in the past, probably due to a sense of security based on the absolute number of valves in most systems.
(Directions of) solutions: Sectioning is a balancing act between a lot of valves with a higher probability of failure but with limited failure consequences or fewer valves with a low risk of failure but more serious consequences. General rules for sectioning are: - Minimise the number of valves (in absolute numbers and for isolating a section) and thus minimise the probability of failure; - Sectioning should be customer driven, since customer dissatisfaction is considered the most critical consequence of failure. Based on experience in the field 120 household-type connections are considered a maximum for simultaneous isolation, because: - This number of connections can be informed quickly and effectively in case of a failure and/or isolation: communication is a crucial factor in the perception of supply problems; - This number of connections will in most cases be located in a geographically

small area, which means that these customers are likely to personally see evidence of maintenance and repair work. This will contribute to more understanding on the part of the customer.

Pipeline length between valves is not an issue for distribution pipelines, except for pipe flushing purposes, where flushing velocity, network characteristics and available pressure determine effective flushing length.

Pipeline length is an issue for transmission mains, where 'tailor made' sectioning should be applied. Section length should be determined based on the time the specific transmission main can be taken out of service. This time is determined by available (emergency) storage and the redundancy of the remainder of the system. In general this means:

Time for dewatering, repairing and refilling < *allowed 'out of service' time*

For transmission mains the time for dewatering and refilling the pipe will often be longer than the actual repair time. Dewatering and refilling time is determined by section length. As a rule of thumb the allowed out of service time would be less than 12 hours.

In assessing the time for dewatering, repairing and refilling the reliability of the complete system has to be considered because a combination of factors will influence how long the customer is inconvenienced:

- reliability of emptying valves which are normally closed;
- reliability of bypass valves for refilling which are normally closed;
- reliability of air valves in case mains have to be exhausted during refilling.

All these valves must work and be operated carefully to minimise customer inconvenience.

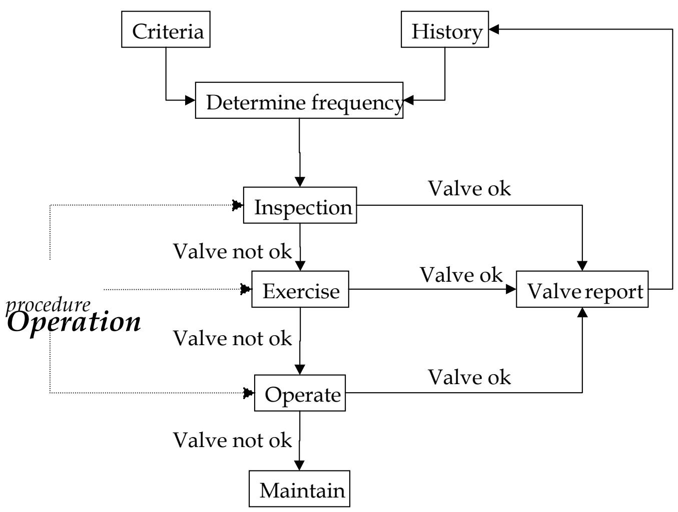
4.4 How to prove valve function reliability? (project sheet)

AWWARF-Kiwa workshop on Operation and Maintenance of Valves
Topic: How to prove valve function reliability?
Description/symptoms: The most basic problem is the definition of valve function reliability. If reliability is not well defined it cannot be proven. Data on the reliability of valves are scarce and a procedure for reliability assessment, based on available data, is often missing.
Possible causes (in order of probability): Possible causes for the inability to prove valve function reliability are: - No adequate definition of valve function reliability and consequently no procedure for reliability assessment; - Little documented information on actual valve function reliability.
(Directions of) solutions: To define valve function reliability it is necessary to define a failure. The following failure definitions have been proposed with regard to reliability: - valve cannot be found (paved over, snow, not identifiable); - valve does not shut down properly (max. acceptable leakage 2.3 m^3/h or 10 gpm); - valve does not re-open after closing; - normally closed valve will not open. If a valve fails on any of the above, it is not reliable. The general feeling is that valve reliability has gone up in recent years because of improvements in valve design. This would mean that for newer systems, the reliability would be determined by the ability to find and access the valves, rather than by valve operation. Based on available data a reliability of 97.5 to 99% for transmission main valves seems reasonable. For smaller distribution on/off valves 95 to 99% seems appropriate.

4.5 Maintenance versus operation

4.5.1 Project sheet

AWWARF-Kiwa workshop on Operation and Maintenance of Valves
Topic: Maintenance versus operation
Description/symptoms: We have the following distributive valve functions: • Isolation with predominantly open or closed valves • Control (throttle) valves for controlling flow, pressure and/or water level • Self acting valves (non return, air release, pressure reduce) We can also classify valves into 'large' and 'small'. In our minds we think about pressure surge, but best practical value for a classification is whether the valve is part of a trunk main or a distributive main. We will focus on predominantly open 'small' isolation valves. Within this field there is a need for tight definitions on operation, maintenance, inspection etc. Things like frequency of inspection are to be described.
Possible causes (in order of probability): Not applicable.
(Directions of) solutions: See figure below and Appendix IV.



4.5.2 Frequency of inspection, exercising and operating: guidelines

The project sheet of the previous paragraph was the outcome of the discussion during the workshop. Determining the frequency of inspection, exercising and operating valves is a key issue in this project sheet. This paragraph presents guidelines for this issue. The text was prepared by Horton Wasserman (Malcolm Pirnie, Inc.).

Valves that have not been inspected and exercised or have not been operated for a period of time may not be available or operable when needed to perform their intended function (isolation of pipeline segments). Therefore, to ensure a high level of system reliability (defined as the probability of being able to isolate a pipeline segment) it is necessary to perform at least some or all of the steps listed in Appendix IV on a periodic basis.

If all valves are at least inspected and exercised or operated frequently and if all identified deficiencies are corrected a very high level of reliability can be expected. However, these steps are not without costs and significant impacts as indicated in Appendix IV. Operating budgets may not be sufficient for frequent implementation of some or all of the steps listed in the Appendices. Improper closure of a valve can have long-term impacts on the distribution system. These include pipe breakage or joint leakage resulting from over pressurisation or waterhammer. In rare cases it may not be possible to reopen a closed valve.

Since a valve cannot be normally exercised without first locating and inspecting these two steps are minimal requirements. Steps beyond inspection and normal exercise will increase costs and perhaps impacts but may not provide a commensurate improvement in system reliability.

Priorities are usually established based on achieving the desired or highest possible system reliability consistent with budget constraints.

Utilities generally agree that inspecting and normally exercising the following categories of valves will provide the most improvement in reliability for the least cost and impacts or to put it another way, the biggest bang for the buck.

1. Valves, particularly critical valves, which have never been inspected and for which there are no inspection reports.

2. Valves, particularly critical valves that are part of a system acquired from another utility.

3. See History below.

Inspection and exercising will also provide information on the initial position of the valve. Closed or partially closed valves may result in stagnant water and reduced fire flows. Closed or partially closed valves on transmission mains increase pumping costs.

Valves falling into the categories listed above should receive the highest priority when scheduling inspections.

There are no universally accepted rules for determining frequency for inspections and the other steps listed in the table. Following (edited for clarity) is from technical references.

1. "Valves should be exercised at least once each year (more often if the water is corrosive or dirty" – Water Distribution Handbook, Larry Mays.

2. From AWWA Manual M44 First Edition (1996)

   - "Inspection (including normal excising) of each valve should be performed on a regularly scheduled bases (annually if possible) and at more frequent intervals for valves 16-inch and larger".

   - "All valves should be cycled from full open to full closed at least every two years. Some types of butterfly valves may have less stringent requirements".

3. Handbook on Valves for Waterworks published by Japan Waterworks.

   Tables require gate and butterfly valves to be operated once each year.

None of the utilities polled complied with the annual frequency suggested by the references. All had longer intervals.

Following are factors, as reported by workshop participants, which are used by utilities to prioritise and determine the frequency of periodic valve inspections and operation:

A. History
B. Type of Valve
C. Criticality
D. Water Quality
E. Age
F. System Impacts

Frequency should be established based on process efficiency which can be defined as the ratio of system reliability improvement and other system impacts (output) divided by cost (input).

A. History

1. Valves may be inspected and operated less often if the current program shows little or no improvement in system reliability (few or no failures) based on the current schedule.

2. If the history shows more frequent problems with a type of valve (gate valve, resilient seat gate valve butterfly valve than the frequency can be increased for the problem type and reduced for valves types which do not exhibit problems.

3. A similar approach can be used based on classifications other than type including:
   - Size
   - Age
   - Water Quality
   - Materials of Construction
   - Manufacturer

B. Type of Valve

1. The type of valve, butterfly (new-old) or gate (metal seat-resilient seat) may influence the frequency particularly if the historical record shows a difference between the reliability of the types. Generally most agree that the reliability of the newer butterfly valves with sealed gearboxes and O-ring seals are about the same as for resilient seat epoxy coated gate valves.

2. The above comment may not apply to newer butterfly valves, which do not have epoxy coatings on ferrous surfaces and are installed in systems having aggressive (corrosive) water.

C. Criticality

1. Failure of valves on large transmission mains will usually result in a longer time (more valves must be closed) to effect repairs required to restore service to large areas and may result in more leak damage than a valve on a small distribution main.

2. Valves on distribution systems in densely populated or industrial or commercial areas may be more critical in terms of the need to minimise leak damage and restore service quickly.

3. Usually failure of larger valves to isolate a pipe break will result in significantly more collateral damage then failure of smaller valves.

4. Since the consequences of failure of critical valves are greater than that of less critical valves consideration should be given to more frequent inspection and operation of critical valves.

D. Water Quality

1. Water that is aggressive (corrosive) may cause precipitates to form on ferrous surfaces of valve closure members particularly surfaces, which do not have adequate protective coatings (epoxy) and also on wetted operating mechanisms. If allowed to build up these precipitates may interfere with valve seating and valve operation. These valves should be exercised and operated more frequently than similar valves exposed to less aggressive water.

2. Certain types of rubbers or elastomers used to fabricate resilient seats may be damaged by exposure to chlorine or chloramines particularly in warmer water. If a change in the treatment process is made which results in a change in the chemical composition of the water consideration should be given to operating a representative sample of the valves to determine if there is leakage resulting from seat damage.

E. Age

1. All things being equal, older valves will be more prone to failure than newer valves.

2. Older valves may not be repairable due to obsolescence. Replacement valves, which may take time to deliver, must be installed. It is usually cost effective to contract for scheduled replacement of a group of valves rather than an emergency replacement of a single valve.

3. Therefore, it may be preferable to schedule frequent inspections of ageing valves to provide an early warning of impending problems.

F. System Impacts

1. As indicated in Appendix IV operating a valve to the closed position can have significant impacts on the distribution system. These impacts are much more significant for larger valves and for valves on transmission mains.

Some utilities limit the steps for valves, which will have significant impacts to those, which do not require complete closure (operation) of the valve while recognising that this does not provide complete assurances that the valve will seat. However, inspection and excising, especially exercising with torque measurement will provide a high degree of confidence that the valve will perform its intended function.

4.6 Problem description for other valve topics

Not all of the thirteen identified valve topics could be discussed and translated to project sheets. Problem descriptions for these topics were discussed briefly and are presented in this paragraph.

4.6.1 Can there be maintenance or only operation?

The problem is that there may be confusion between maintenance and operation. The question is for example whether or not exercising a valve is the same as operating a valve. Operation of a valve normally means full shutdown and reopening, whereas exercising might not include full shutdown, so shutdown will not be tested.
Questions are:
- Should maintenance be seen apart from operation?
- How to prioritise maintenance activities (big/small)?
- How cost-effective and efficient are specific maintenance activities?
- How to organise maintenance activities during regular valve operation?

What is the definition of maintenance: what exactly are maintenance, inspection, exercising and operation? Are these all maintenance activities?

Direction of solution (from Roland L. Larkin, American Flow Control)
Maintenance and operation need to be addressed as completely separate issues. Operation (or exercising) is a routine function to determine if a valve will operate. Maintenance is the repair of a valve after it has been determined that the valve did not properly operate. The only aspect of the operating cycle that could be considered maintenance is the cleaning of the valve that may occur because of operation.

4.6.2 Valves and fire protection

In the workshop it was decided not to focus on this subject, based on the following considerations:
- The probability of a main being off-line during a fire is very low.
- Alternative hydrants or alternative water sources are usually available.
- The issue of fire protection with regard to water supply should be dealt with in another discussion (AwwaRF-Kiwa Impacts of fire flow project).

Valves and fire protection are not entirely independent. Serious losses from fires (and major lawsuits) because fire flow was not available as a result of an inadvertently closed valve have been reported.

As for valve selection providing fire flows can be a criterion:
- Full bore valve preferred.
- Pressurised hydrants vs. hydrant on a lateral.

4.6.3 *Standards: international versus national*

The problem is that there are no international standards for valve design and valve selection. Existing standards are mostly national. Therefore differences in international risk assessment are likely. This may however be a matter of opinion more than a matter of reality. This should be investigated.

4.6.4 *Distributive valves*

The scope of the workshop is on on/off valves in drinking water transmission and distribution. Other valve functions (throttling, nonreturn valves) were not discussed. The question is whether they should be discussed. Over 90% of the valves in the transmission and distribution system are on/off valves. Non return valves typically are not used in the distribution lines. They are normally used in treatment plants or pumping stations and therefore beyond the scope of the workshop. For special valves it is hard and probably not necessary to give general recommendations with regard to operation and maintenance. Manufacturer's instructions or recommendations should be used.

4.6.5 *Define the function of a valve in the system*

Defined functions:

- Blocking of waterflows
- Isolation of section of pipe for repair, maintenance, testing and redirect flow for hydraulic reasons and for separating waterqualities

Function definition combined with an analysis of specific constraints is necessary to select the type of valve best suited for a given function.

During the workshop the group discussing this topic redirected the discussion towards the placement of valves with regard to system reliability. The results of this discussion are presented in a separate Kiwa report on "Requirements for valves from a customer's point of view" (BTO 2001.156 (s)).

4.6.6 *Type of valve: function and reliability*

There is no specific information on the relation of valve type (butterfly/metalseated gate/resilient gate) and reliability and how specific factors influence reliability. Factors mentioned are:

Water quality	Earthquakes
Energy loss	Pipe diameter
Depth of cover (freezing)	Pressure
External corrosion	Water velocity

In discussing the factors that influence reliability, it may be wise to group these factors in several categories:

- Factors that affect water quality: internal corrosion, type of valve operation;
- Factors that affect pigability: internal corrosion;
- Factors that affect valve function: pressure, earthquake, velocity (cavitation), internal and external corrosion, etc.

Information on these factors is desired for maintenance optimisation and – in case of new systems or rehabilitation - for selecting the type of valve best suited to avoid operational problems.

The question 'How to quantify reliability?' is dealt with in another topic.

5 Recommendations

From the project sheets, some basic recommendations can be derived on valve operation and maintenance and specifically on answering the questions that are still open and the items that need further attention in research. Recommendations of the separate Kiwa report on "Requirements for valves from a customer's point of view" (BTO 2001.156 (s)) have also been included.

Valve location

- Use clear and uniform section criteria based on an analysis of failure probability, valve reliability and failure consequences.

Valve operation and maintenance

- Provide clear and uniform operation and maintenance procedures. These should include the gathering of information on the status and condition of the valve.
- Document information on actual valve reliability and on consequences of unreliable valves.
- Provide clear and uniform procedures for valve operation, inspection and exercising. Register and analyse the data to find trends and to establish inspection intervals (see future research).
- Incorporate pragmatic operational tools in network information systems to facilitate quick section analysis. This can be extremely helpful in case of an emergency.

Future research

- Put valves higher on the research agenda. Despite their presence in high numbers and their important role in the distribution system, little is known about their performance, their reliability and the consequences when they fail.
- Define and assess valve function reliability. In order to do this research should concentrate on reliability of single valves, valve location and establishing reasonable reliability criteria.
- Establish inspection, exercising and operation frequency based on a return-on-investment analysis. Research should focus on providing key figures for inspection, exercising and operation, as well as the return in terms of system reliability improvement and other benefits.
- Determine how factors such as age, water quality, soil conditions, hydraulics, etc. influence the reliability of valves in order to predict valve condition and establish inspection, exercising and operation intervals.
- Develop an easy-to-use tool for reliability analysis for complicated networks. It will be a challenge to find or develop a mathematical rule for calculation of system reliability in order to make automatic calculations possible.

- Develop a strategic ‘valving’ tool for assessment of system security investments. The tool should be able to assess best investment policy by balancing between investments in limiting pipe failures, smaller sections, more reliable valves (valve selection, intensive valve control program) and damage control.

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I Workshop program

<u>**Program for the AWWARF-Kiwa Valves workshop**</u>

Thursday, March 29

09.00 Start and personal introduction
10.00 Literature review, presentation by Loet Rosenthal
10.30 Results of the questionnaire, presentation by Martin de Koning
11.00 Define topics to be discussed;
Set working procedures for the workshop
11.30 Problem definition and defining priorities (in subgroups)
12.30 Lunch

13.30 Review of problem definition (plenary session)
14.15 Problem analysis (discussion in subgroups)
16.15 Produce preliminary reports
17.30 Summary and program for Friday, March 30

Friday, March 30

09.00 Startup
09.30 Problem analysis and solutions (in subgroups)
11.30 Produce draft reports
12.30 Lunch

13.30 Review of problem analysis and solutions (plenary)
14.30 Define remaining topics
15.00 Quick analysis and defining possible solutions
16.00 Produce reports
17.00 Evaluation and close.
18.00 End

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III Questionnaire respondents

Utilities

Brisbane City Council - Brisbane Water
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Power & Water Authority (Northern Territory)
Winnellie, Northern Territory, Australia

Sydney Water Corporation
Sydney, Australia

Melbourne Water
Mt. Waverly, Victoria, Australia

South East Water Ltd
Moorabbin, Victoria, Australia

Hunter Water Corporation
Newcastle West, New South Wales, Australia

Antwerpse Waterwerken N.V.
Antwerpen, Belgium

Waterleiding Maatschappij Overijssel N.V.
Zwolle, The Netherlands

Waterbedrijf Europoort
Rotterdam, The Netherlands

SMAS – Serviços Municipalizados de Água e Saneamento
Lisbon, Portugal

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Harrington Park, NJ, USA

Rand Water
Johannesburg, RSA

Fukuoka City Waterworks
Fukuoka, Japan

Chiba Prefecture Waterworks
Chiba, Japan

Yokohama City Waterworks
Yokohama, Japan

Kobe City Waterworks
Kobe, Japan

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ODS B.V.
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PCC Wouter Witzel Eurovalve
Enschede, The Netherlands

IV Valve operation and maintenance in practice

Normally Open Valves

Steps	Define	Information Received	Tools Required	Possible Impacts	Actions to do	Data to Collect
Inspection	Location, Site conditions	-accuracy of location –accessibility –condition of valve box and cover –condition of nut –position of indicator (if available) –leakage of seals or stem	Safety equipment as necessary (i.e., working in high traffic areas), Flashlight, T-handle, Plans/Maps, Previous Records, Valve Reports, location devices, tape measure	Disrupt traffic (vehicular and/or pedestrian) flows	Traffic control plan	Location, external condition
Exercise –Normal	Check working condition of valve by closing to approximately 50%	-is valve operable –initial position (i.e., was valve fully open?) –validity of position indicator –tracking of trends	Same as for Inspection	Disrupt traffic (vehicular and/or pedestrian) flows, dislodging of sediments and pipe deposits, may require operation	Traffic control plan, customer notification	Availability for working correctly, position of the valve
Exercise –with Torque	Check working condition of valve by closing to approximately 50%, measure	-is valve operable –initial position (i.e., was valve fully open?) –validity of position indicator –condition of operating	Same as for Inspection, torque measuring device	Disrupt traffic (vehicular and/or pedestrian) flows, dislodging of sediments and pipe deposits, may	Traffic control plan, customer notification	Availability for working correctly, position of the valve, value of the operating torque

	torque of operating mechanism	mechanism –tracking of trends		require operation		
Operation –Normal	Check working condition of valve by fully closing and opening –measure torque –check for leakage past closed valve	-is valve functioning correctly (will valve close?) -verify number of turns	Same as for Inspection	Disrupt traffic (vehicular and/or pedestrian) flows, resuspension of sediments, interruption of service to customers, surge, may require flushing of system, may require maintenance	Traffic control plan, notification of customers and authorities	Verification of the number of turns, ability to close.
Operation –with Torque	Check working condition of valve by fully closing and opening –measure torque	-is valve functioning correctly (will valve close?) -verify number of turns –more data on operating mechanism (torque)	Same as for Inspection, torque measuring device	Disrupt traffic (vehicular and/or pedestrian) flows, resuspension of sediments, interruption of service to customers, surge, may require flushing of system, may require maintenance	Traffic control plan, notification of customers and authorities	Verification of the number of turns, ability to close, maximum torque,

Operation –with Sonic	Check working condition of valve by fully closing and opening –measure torque –check for leakage past closed valve	-is valve functioning correctly (will valve close?) -verify number of turns –seat leakage, seal leakage	Same as for Inspection, leak detection device	Disrupt traffic (vehicular and/or pedestrian) flows, resuspension of sediments, interruption of service to customers, surge, may require flushing of system, may require maintenance	Traffic control plan, notification of customers and authorities	Verification of the number of turns, ability to close, if leakage is present or not.
Maintenance	Repair or replacement of valve	NA			Traffic control plan, notification of customers and authorities, repair (i.e., lubrication, packing adjustment, etc.) or replacement	All reasons for maintenance