ABSTRACT

Recent studies on the management of water resources evaluated in ten billion Euro the yearly financial expenditure of European cities for networks rehabilitation. Those who believe in the evidences of the analysis loudly complain the fact that the rationale behind rehabilitation decisions has been up to today at the best unclear, with interventions usually based on local practical experiences. Nevertheless, even those who distrust such “dark” estimations have to admit that most of the old continent is supplied by old systems; nor they can deny that the relevant aging problems of the networks are likely to result in a significant increase of maintenance expenses in the decades to come.

The history of water networks rehabilitation leans on the so called re-active approach: first the failure occurs, then comes the intervention. Efforts are recently being undertaken in order to establish a rational framework for maintenance decision-making in water distribution systems, based on a new logic: a rehabilitation carried out before the problem takes place is to be preferred, thanks to its higher effectiveness and to the troubles it is able to prevent rather than cure (pro-active approach).

This paper presents an Italian experience in the study of water networks rehabilitation methods, jointly conducted by Bologna University (D.I.S.T.A.R.T. Department) and Ferrara University (Architecture Department).

The first part of the work describes a typical “reactive” activity, a leak detection campaign carried out during September 2001 on the water distribution system of Mirabello, a small city in the province of Ferrara. The campaign was a test-bench for “Permalog”, an acoustic leak detector, never used before in the area at issue, whose interesting performance could be highly exploited in future research activities.

The second part of the work deals with the participation of Bologna and Ferrara University to CARE-W (Computer Aided RE-habilitation of Water Networks), a research project supported by the European Commission under the Fifth Framework Programme, contract n° EVK1-CT-2000-00053. First the project is introduced, its final goal stated and its on-going results reported; then two works are presented, one dealing with pipe breaks data collection and elaboration in Regione Emilia-Romagna (a preparatory activity to CARE-W itself), the other one showing an applied example of multi-criteria rehabilitation analysis (to be used in the development of the project’s Decision Support System).

KEYWORDS: networks rehabilitation, water distribution system, leak detection, mean break rates, multi-criteria analysis.
INTRODUCTION

It is a fact that water distribution systems in most European cities are reaching the end of their lifetime; pipe breaks and leaks have had a significant increase in the last years, and there is no evident reason for the future trend to be inverted in the short-term horizon.

On the other hand, it is a fact as well that management planning methods have been characterised by a poor development; this is particularly true if we consider that networks rehabilitation have already involved huge financial expenditures throughout the continent, and things can only get worse in the coming years.

A clear need came out for the establishment of a rational framework for rehabilitation decision-making processes. The European Project CARE-W (Computer Aided RE-habilitation of Water Networks) intends to address these problems; its ultimate goal is the development of a suite of tools able to guide responsible entities to rehabilitate the right pipelines at the right time using the right technique. The whole process should take place at the minimum total cost and, above all, before failure occurs (pro-active approach).

Indeed, the re-active logic will take a long time to be overcome. Attention should be paid as well to the necessary interactions between the two logics: in order for the pro-active approach to work well, a quantity of data are requested, part of them to be collected after mains failed (i.e. pipe breaks and consequent leaks).

The present note describes the initiatives undertaken by Bologna and Ferrara University in the study of suitable methods for water resources management. As the reader can guess, the activities inherent to such a vast field are the most variegated, ranging from statistical elaboration of pipe breaks data for the assessment of the hydraulic reliability of the network, to the development of a multi-criteria procedure for the choice of the mains to rehabilitate, and to in-field application of innovative techniques for leak detection. All of these will be presented in the following paragraphs.

1. PROPOSAL OF AN OPERATIVE PROCEDURE FOR LEAK DETECTION IN WATER DISTRIBUTION NETWORKS

The reduction of losses in a water supplying system is a key issue with respect to the achievement of the required standards of efficiency. Some urban distribution networks are characterised by extremely high values for water losses, which may even reach the 30 or 40% of piped resources.

Leak detection is usually seen as quite a hard and expensive activity to be carried out, because of the considerable amount of human and financial resources it requires; the introduction of innovative tools, able to lower down the active involvement of the Agency in such an activity by means of automatic procedures, may therefore prove themselves to be of the highest effectiveness in this field.

The Architecture Department of Ferrara University recently provided itself with “Permalog”, an acoustic leak detector consisting of a central unit (Patroller) and fifteen noise loggers. In conjunction with Bologna University, D.I.S.T.A.R.T. Department, a campaign was realized aiming at defining a proper and complete procedure for the localization of undetected water losses. The small town of Mirabello, in the province of Ferrara, was selected for the activities; with its overall pipe length of 25 km and about 2000 users supplied, the distribution network at issue had revealed abnormal high values of night flow rates, so that it was proposed by ACOSEA, the agency responsible for the water supply service in the area, for the analysis.

1.1 AN INTRODUCTION TO PERMALOG

Thanks to the high strength magnet on their base, Permalog noise loggers can be attached to metal pipe fittings throughout the distribution system to provide continuous surveying of leakage. Each logger is able to “listen to” the noise level close to itself at various intervals during the night, and then transmit a signal indicating a LEAK or NO LEAK condition. The Permalog Patroller module receives and analyses these signals, identifying the location of units in LEAK mode and thereby the approximate position of the leaks.

The Patroller displays four kinds of data: a) the serial number of the detected logger; b) the noise level in dB from the logger: \( L_v \); c) the noise spread in dB from the logger: \( S_p \); d) the time or date the data was received from the logger. The second and third information are the most important ones; leaks are detected through a combined analysis of them two, and are typically characterised by high values for \( L_v \) associated to low levels of \( S_p \). The first requirement, in fact, is not representative by itself of a pipe failure, since it can simply be due to a strong noise (e.g. heavy traffic); a low spread, then, signifies the presence of a steady phenomenon, arousing the suspicion of a leak. The whole procedure is made quite easy by the fact that the Patroller only needs a common lighter socket to work, thus can be used on board of every kind of car.
As an acoustic detector, Permalog leans on the transmission of sound waves along pipes, an effect strongly depending on the crossed material (with plastic mains obviously altering the signal more than metal ones).

### 1.2 THE FIRST PART OF THE CAMPAIGN

On September 2002, 19th and 20th, a first leak detection campaign was carried out by two engineers coming from Ferrara and Bologna Universities, with the precious assistance of one technician from ACOSEA and of Eng. Hans Brand; since this campaign availed itself of 64 loggers, 15 owned by Ferrara University plus 49 kindly placed at disposal by Eng. Hans Brand, it was possible to cover the whole network of Mirabello. The loggers were deployed on valves inside traps (when this was not possible, gates and/or private meters were used) at regular intervals along the system. Taking into account the different transmission of the acoustic signal mentioned in the previous paragraph, the distance between two consecutive loggers was 80-100 metres and about 150 metres respectively for underlying plastic and asbestos cement pipes.

Once deployed, the loggers were left in field for one night so to give them time to record noise levels. The morning after the deployment a survey was carried out in the area with a car equipped with the Patroller, and signals were collected coming from all of the loggers. Three of them were found to be in LEAK mode, one along via Argine Vecchio ($L_v$: 58 dB / $S_p$: 7 dB), two along via Masetti (28/4 dB; 35/3 dB).

According to the data received, three possible leaks were present in the network, not too far from the above loggers; yet, the Permalog is unable to localize the problem with any more accuracy.

Further analysis were required in order to select the actual point for the excavation, and they were carried out by means of a correlator in a first phase and of a geophone in a second one.

The use of correlator and geophone along via Argine Vecchio led to the proposal of a point for the excavation. The digging activities took place five days after the first campaign, on September 25th: two leaks were found close to each other (one on a 110 mm diameter PE distribution main, the other one on a service connection; indeed, two nearby peaks were perceivable by means of the geophone), and the localization proved almost perfect (the failures actually were at a 50 cm distance from the chosen point).

About the two loggers in LEAK mode along via Masetti, the analysis with the correlator and the geophone confirmed, as expected, that both of them were indicating one single leak. In fact, a leak was present and already visible in via Masetti (on the 80 mm asbestos cement pipe supplying the street) at the time the campaign was realized, and the street at issue was surveyed as a test-bench for Permalog (its effectiveness strongly reappraised if it had failed in such a case).

### 1.3 THE SECOND PART OF THE CAMPAIGN

One of the most interesting characteristics of Permalog is that it is able to provide continuous surveying of leakage; this means that, once deployed, the loggers can be left working. A leakage patrol carried out with the module at regular intervals allows the agencies to monitor the evolution of their network.

The loggers used during the first campaign were then left in field for one week, so to check the consequences of repairs on noise levels. Surveys with the Patroller were conducted on September 26th and 27th (the second one using only the 15 loggers owned by Ferrara University); the correlator and the geophone were not available this time, so no further investigation could follow any new detection.

As expected, no relevant noise was any more reported by the logger placed along via Argine Vecchio. About the other street investigated during the first part of the campaign, i.e. via Masetti, the logger closer to the visible water loss presented low values of $L_v$ after the repair, while the other one still kept on the LEAK mode; as a clearing up of this point, ACOSEA reports that in the first days following the second campaign a new leak was found at another point of the asbestos cement pipe running beneath via Masetti.

Indeed, the survey brought about new results: a logger at a crossing between via Argine Vecchio and via Vittorio Emanuele presented suspect values (11/4 dB), a second one was found in WARNING mode (an intermediate level between LEAK and NO LEAK: 18/5 dB) at the crossing between via Sessa and Corso Giovecca, and two loggers were in LEAK mode, one along via Sessa (25/2 dB) and the other one along Corso Italia (45/6 dB). All of these alarms were followed by real evidences: two leaks were found on service connections in via Vittorio Emanuele and Corso Giovecca within a week thanks to customers’ complaints, and water was visible in via Sessa on the morning of September 28th. About Corso Italia, technicians of ACOSEA had been suspecting for a long time the existence of a leak along the central street of the town, but it still took some weeks to be localized and repaired (not far from the logger).
1.4 RESULTS

The most important result of the campaign is the detection of the two leaks in Via Argine Vecchio; as evidenced in figure 1, the hourly mean flow rate leaving the tank supplying Mirabello at 4:00 in the night dropped down for more than 1.5 l/s from September 25th to 26th, i.e. after the pipe had been repaired.

Indeed, the overall performance of the Permalog was very good, and could be summed up in a sentence: all of the real leaks were detected by Permalog, all of the leaks detected by Permalog were real. Figure 1 still show an interesting phenomenon, that is an increase in the night flow rate in the days following the interventions. In order to understand such a behaviour, let us consider that the network at issue actually lays in poor conditions; on the one hand the repair carried out on September 26th prevented ACOSEA from further wasting water, but on the other one it provoked an overpressure in the system which eventually resulted in the numerous failures registered in the days following the campaign.

Last but not least, it is worth underlying that Permalog is not at all a self-sufficient tool for leak detection. As stated before, it is unable to localize a water loss accurately enough to proceed with excavation and repair; yet, its proper use increases the efficiency of the tools following it.

The described activities led then to the definition of an appropriate procedure for leak detection, based on the combination of three devices: an acoustic detector, an electronic correlator and a geophone. If used following the proposed sequence, these tools enable the inspector to zoom in only those areas deserving further investigations, with the relevant reduction in economic and human resources such a targeted analysis would surely bring about.

2. THE EUROPEAN RESEARCH PROJECT CARE-W

In the introduction to this work the importance was stressed that a rational framework for rehabilitation decision-making be built up and a new approach be sponsored, according to he logic that “preventing is better than curing”. These ideas lay at the basis of the Research Project CARE-W (Computer Aided RE-habilitation of Water Networks), supported by the European commission under the Fifth Framework Programme, contract number EVK1-CT-2000-00053.

The project deals with public water supply networks and their problems of ageing such as structural failures, hydraulic insufficiencies, leakages, deteriorating water quality and increasing maintenance costs impacting on an urban environment. Its ultimate goal is to develop a suite of tools which provide the most cost-efficient system of maintenance and repair of water distribution networks, with the aim of guaranteeing a security of water supply that meets social, health, economic and environmental requirements.

CARE-W is therefore addressed to utilities for water supply systems, operating companies, local authorities, financial institutions and national regulators (Saegrov et al., 2002).
2.1 CARE-W OVERVIEW

The project avails itself of 11 partners (universities, research institutes and water companies) coming from 7 European countries: Czech Republic, Deutschland, France, Italy, Norway, Portugal and United Kingdom. In addition to them, 12 cities from 8 European countries (the same as the partners plus Switzerland) are included as end users. Some partners have a similar background, but their experience comes from different regions with different strategies to tackle rehabilitation problems. CARE-W is divided into seven technical work packages, each with its own objectives, but linked to the other ones.

Work Package 1 is dedicated to Performance Indicators, which are parameters (e.g. water losses or failure rates) able to express the performance of a water undertaking with respect to the rehabilitation framework. 30 Performance Indicators have been selected within CARE-W; together with 84 Utility Information (directly related to the activity of the utility and under its direct control, like mains length per material, water losses and average operating pressure) and with 15 External Information (not influenced by the utility critical for establishing the rehab diagnosis, like rainfall, temperature or type of soil), they have a strong influence on the decision making process within the project. Objective of WP1 is the construction of a control panel of PIs and the development of a specific software for their forecasting (Alegre et al., 2000).

In Work Package 2 two different kind of tools, the Statistical Failure Forecasting Models and the Hydraulic Reliability Models, previously developed by some of the partners, are analysed, tested and validated (Eisenbeis et al., 1999). Since their objectives and results partially overlap, a procedure for the selection of models in practical situations will be established.

Work Package 3 and Work Package 4 respectively deal with the short and medium-long term rehabilitation planning in water undertakings.

WP3 analyses the various rehab techniques with respect to different points of view (rehabilitation costs, water losses, damages and disruptions caused by leaks, …), and then combine the rank thus obtained by means of a multi-criteria procedure so to have a final overall ranking of the techniques.

WP4 uses different parts of the Kanew software to: a) create consistent paths into the future development of the water company (Scenario Writer); b) simulate the effects of medium and long term rehabilitation strategies (Rehab Scenario Manager); c) compare alternative rehabilitation programmes, in order to find the most appropriate rehab strategy (Rehab Programme Evaluator) (Herz & Lipkow, 2002).

Work Package 5 is dedicated to the Prototype, a software which will handle inputs and outputs from the different Work Packages and will therefore represent the heart of CARE-W. The product of WP5 will be the final output of the project, since the Prototype will allow the user to choose whether the whole rehabilitation procedure is required or else partial specific tools will suffice for its planning needs.

Special attention will be paid to the testing and evaluation of the Prototype, which will be carried out in Work Package 6. Finally, the dissemination phase deserves a Work Package by herself, Work Package 7. National and international conferences will be held to present CARE-W and its results, the project will be introduced in educational programmes at Universities or higher technical education level; the official web-site of the project is already active and regularly updated with working progresses (www.unife.it/care-w).
2.2 CONCLUSIONS

A system for water network rehabilitation planning is under development in the EU Fifth Framework Programme for Research and Development. The system will include recommended performance indicators for water supply networks, tools for failure prediction and water supply service reliability analysis, methods for comparing rehabilitation projects and measures, and methods for long-term strategic planning and investment. These elements will be combined in the CARE-W prototype, a tool for consistent water network rehabilitation planning whose final aim is helping responsible entities to solve the problem on when, where and how to rehabilitate. In a few words, the philosophy of CARE-W is “rehabilitating the right pipe at the right time and with the right technique”.

The prototype will be tested in 12 cities representing different European conditions; the development consortium will offer training to end-users and will integrate the findings in higher education courses. Initiatives are actually being undertaken in order to involve partners and users coming from Newly Associated States within the CARE-W consortium. CARE-W project will run until spring 2004.

3. ANALYSIS OF PIPE BREAKS IN A WATER SUPPLY SYSTEM

A recent Italian law, the so-called “Legge Galli”, introduces new concepts in the management of water services. A major factor for the fulfilment of the law requirements is the reduction of water losses and the improvement of reliability; analysis of pipe breaks in the network is essential for reliability evaluation.

In order to develop and test a standard methodology for pipe data analysis, the distribution system managed by CADF (Consorzio Acque Delta Ferrarese) was selected for a study of pipe breaks during the years 1995-2000. The activities were organized as follows. First, a standard recording format was developed to collect and classify pipe break data and other information from networks with widely different structure and characteristics. Second, data were analysed to determine the distribution of breaks in space and time.

These activities were carried out as preparatory to CARE-W, the European Research Project described in the previous paragraph; in more details, they are being used in WP1 (in determining PIs, UIs and EIs), WP2 (for implementing the statistical models) and WP6 (reference values in the testing of the Prototype).

3.1 DATA COLLECTION METHODOLOGY
The available data on the water distribution network were subdivided into two blocks: data concerning the system and data concerning breaks. A twofold database was created for the purpose, the first section containing the characteristics of every network link (localization, diameter and material of each main), the second one including information relative to single failure events (as available in the 50,000 repair logs filled in on paper by CADF). Efforts were made in order to avoid the registration of data inherent failure events due to external causes (excavations close to pipes, works on other utilities, etc.).

Once registered, data were analysed to determine the characteristics of the network and the distribution of breaks in space and time; the yearly and seasonal mean break rates were evaluated for each material, to individuate significant trends in time and non-homogeneities in the break spatial distribution.

As for the characteristics of the overall system, covering an area of 1312.6 km² on the coast of Emilia-Romagna and supplying about 110,000 inhabitants (increasing to 200,000 during summers), it was found to rely on several smaller networks serving a number of communities and connected by transmission mains. Many materials are represented in the 1863.49 km of total length of the network, and are shown in table 1:

<table>
<thead>
<tr>
<th>Material of the pipes</th>
<th>Total length (km)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>69.26</td>
<td>3.72</td>
</tr>
<tr>
<td>Concrete</td>
<td>32.13</td>
<td>1.72</td>
</tr>
<tr>
<td>Asbestos Cement</td>
<td>1263.56</td>
<td>67.81</td>
</tr>
<tr>
<td>Iron</td>
<td>4.21</td>
<td>0.23</td>
</tr>
<tr>
<td>Grey Cast Iron</td>
<td>3.51</td>
<td>0.19</td>
</tr>
<tr>
<td>Nodular Cast Iron</td>
<td>87.35</td>
<td>4.69</td>
</tr>
<tr>
<td>Unknown</td>
<td>40.01</td>
<td>2.15</td>
</tr>
<tr>
<td>PE</td>
<td>48.08</td>
<td>2.58</td>
</tr>
<tr>
<td>PVC</td>
<td>315.38</td>
<td>16.92</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1863.49</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

The materials constituting the pipelines vary widely among the local networks, depending on the replacement policy followed locally by the managing Agency in the past decades. Overall, more than half (67.81%) of the pipelines are made of asbestos cement, PVC accounts approximately for 17%, nodular cast iron is about 5%, steel is about 4% and all other materials are under 3%.

2844 break events relative to the period 1995-2000 were registered in the electronic database for further analysis; date, place, material and diameter of the interested pipeline were reported for each event, plus additional information (e.g. man-hours necessary for repair) in some cases.

The mean break rate for the whole period was computed by dividing the total number of pipe breaks for the length of the distribution network; it is shown in table 2 and hereinafter as breaks per year and per km:

<table>
<thead>
<tr>
<th>Year</th>
<th>Breaks</th>
<th>Breaks per year and per km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>278</td>
<td>0.149</td>
</tr>
<tr>
<td>1996</td>
<td>405</td>
<td>0.217</td>
</tr>
<tr>
<td>1997</td>
<td>560</td>
<td>0.301</td>
</tr>
<tr>
<td>1998</td>
<td>515</td>
<td>0.276</td>
</tr>
<tr>
<td>1999</td>
<td>541</td>
<td>0.290</td>
</tr>
<tr>
<td>2000</td>
<td>543</td>
<td>0.291</td>
</tr>
<tr>
<td><strong>Total/Mean</strong></td>
<td><strong>2844</strong></td>
<td><strong>0.254</strong></td>
</tr>
</tbody>
</table>

The total number of failures per year and consequently the mean break rate per year are found to increase significantly during the first three years of the study, and then remain more or less constant; such a behaviour is likely due to an improvement in the registration procedures of breaks rather than to a substantial worsening of the network conditions from 1995 to 1997. The mean break rate for the whole CADF network is 0.254; the value is comparable to that obtained for other Agencies in Regione Emilia-Romagna (Bizzarri et al., 2000): 0.155 for AGAC – Reggio Emilia, 0.294 for ACOSEA – Ferrara, 0.202 for AREA – Ravenna, 0.159 for AMI – Imola and 0.168 for SEABO – Bologna.
The study of the distribution of breaks along the year showed a relevant increase during summer throughout the whole network, such a seasonality probably due to tourism-related overpopulation. This is in contrast with experiences carried out in U.S., where a major portion of breaks occurs during winter (O’Day, 1982).

As for mean break rates for different materials, the highest value was found for PE (Polyethylene) and the lowest for NCI (Nodular Cast Iron) and C (Concrete). The high break rate for PE (0.93) should not necessarily be linked to poor mechanical characteristics; since PE is generally used for low diameter distribution pipes, it is commercialised in rolls which are often stored improperly (no protection from sun rays and heat). For AC (Asbestos Cement) the break rate is 0.27; this value is close to the overall Mean Break Rate (0.254); this is understandable, as AC is used in 68% of the network. The number of breaks during the period of the analysis (1995-2000) decreases for AC (from 75% to 72%) and increases for plastic materials (from 18% to 20%); this happens because during the last years the broken AC pipes have been replaced with PE or PVC pipes, increasing the probability of failure of the latter.

In order to determine the influence of the diameter on break rates, four diameter-based classes were identified: classes 1 to 3 include pipes with diameters respectively lower than 42 mm, between 45 mm and 150 mm, higher than 150 mm, while all the pipes with unknown diameters were grouped into class 0. Pipes in class 2 were found to be affected by 65% of the total breaks; such a high value is due to the fact that diameters from 45 mm to 150 mm are typical of distribution networks. On the other hand, the percentage related to class 1 should be deemed as grossly underestimated, since low diameter pipes (< 42 mm) are typically used for service connections, and break events concerning the latter, when identified as such, were left out from our investigation. Pipe break rates were found to depend inversely on diameter, confirming literature findings (Su et al., 1987; Quimpo & Shamsi, 1991): the mean number of breaks per year and per km of pipe is 0.406 for diameters lower than 42 mm (class 1), 0.279 for diameters ranging between 45 mm and 150 mm (class 2) and 0.107 for higher diameters (class 3).

3.2 CONCLUSIONS

Under the present legislation Italian water distribution systems are required to achieve higher management efficiency; in urban networks the reduction of water losses is a key issue in reducing costs and improving the serviceability. To achieve this goal, this study created a twofold electronic database and filled it in with data regarding either network characteristics and relative breaks events coming from the archive of CADF, an agency managing a water distribution system in the Italian region Emilia-Romagna. The database is functional to produce statistical elaborations of the information herein included, leading to the calculation of important parameters regarding the system itself (mean break rates, in particular, allow comparisons among different agencies in terms of reliability and performances).

With respect to possible future developments, the database constitutes an useful basis for further analysis of the network. The integration of data with geographic information, made available by the adoption of a GIS, together with the necessary updating of the cartography, will enable more detailed analysis in the future which will result in a higher level of knowledge of the condition of the system and of its functioning.

4. DECISION-MAKING SUPPORT METHODS FOR THE REHABILITATION OF WATER DISTRIBUTION NETWORK

As stated before in this paper, support methods to decision-making in water network rehabilitation are strongly needed in order to increase the effectiveness of interventions and to achieve the result of “rehabilitating the right pipelines at the right time with the right technique and with the lowest overall cost, before failure occurs”.

The outlines of the decisonal support procedures developed within the CARE-W framework (WP1 and WP3) will be presented in the following paragraphs. First those PIs will be introduced that have been added by the work group to the list proposed by the International Water Association (IWA) (Alegre et al., 2000). Then some technical, economical and social criteria will be defined for the evaluation and ranking of potential interventions with respect to different points of view. Finally, some existing multi-criteria procedures will be analysed, selected and adapted for the purpose of the study.

4.1 THE NEW PERFORMANCE INDICATORS
The use of Performance Indicators is a routine procedure in many industrial sectors; indeed, water undertakings only in the last years started appreciating the potential benefits of such tools, probably because of their nature of public service and of monopoly. IWA recently developed a standard for the principal PIs. The CARE-W consortium formulated an autonomous set of 30 Performance Indicators; most of them are more or less directly linked to the list proposed by IWA, while 5 indicators are brand new and have been defined specifically for the sake rehabilitation planning. The latter PIs are reported in table 3:

**Table 3: new Performance Indicators**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Op26e - Critical mains failures (No./100km/year)</td>
<td>Number of mains failures in sensitive areas during the year / total mains length in sensitive areas x 100</td>
</tr>
<tr>
<td>QS12a - Critical interruptions per connection (No./1000 connections)</td>
<td>Number of supply interruptions to sensitive service connections during the year / number of sensitive service connections x 100</td>
</tr>
<tr>
<td>QS25a - Water taste complaints (%)</td>
<td>Number of water taste complaints during the year / number of service complaints during the year x 100</td>
</tr>
<tr>
<td>QS25b – Water colour complaints (%)</td>
<td>Number of water colour complaints during the year / number of service complaints during the year x 100</td>
</tr>
<tr>
<td>QS26a – Critical interruptions complaints (%)</td>
<td>Number of complaints due to supply interruptions to sensitive service connections during the year / number of service complaints during the year x 100</td>
</tr>
</tbody>
</table>

**4.2 CRITERIA FOR THE EVALUATION OF REHABILITATION INTERVENTIONS**

Decision support methods are specially intended to allow comparisons among intervention alternatives which are deemed more or less effective with respect to predefined points of view. Those points of view have been considered that are linked to the typical problems encountered in the management of a water distribution network:

- reduction of rehabilitation and coordination costs;
- reduction of service interruptions;
- reduction of the risk of damages and disruptions;
- reduction of water quality problems;
- reduction of water losses.

Taking into account a point of view means realizing a method which is either of support to rehabilitation decisions and able to improve the conditions of the network with respect to that single point of view.

*Figure 3* shortly represents the procedure followed in the building up of decision support methods:

---

**Figure 3: the building up of methods**
Each method consists of both a generic approach and some general and specific procedures. The generic approach varies from one point of view to another: to give some examples, guidelines for the estimation of real costs are proposed in the point of view “Reduction of rehabilitation and coordination costs”, while no generic approach is provided for the points of view “Reduction of water quality problems” and “Reduction of water losses”.

General procedures contain all the necessary information required by a single point on view; as from a set of starting data a series of sub-criteria may be calculated, which in turn will be functional to the elaboration of the final criteria. Specific procedures develop from the general ones; thanks to the more detailed data required, they are to be implemented directly onto the i-th main rehabilitated with the j-th technique.

Special attention has been paid to the fact that the different final end-users of the methods may have different accuracy of available data. As a consequence, three approaches were developed within each specific procedures: L0 – qualitative, L1 – quantitative and L2 – detailed quantitative.

All of the procedures lead as a final result to a numerical value, called “Net Improvement” (I); it is an index expressing how far the conditions of the i-th pipe are improved by the implementation of the j-th technique.

4.3 MULTI-CRITERIA PROCEDURES

In this phase of the work some existing multi-criteria procedures were examined, selected and adapted to the evaluation and the comparison of different potential rehabilitation interventions. In particular, tests have been carried on the “Electre tri” method, belonging to the Electre family of methods (Lamsade, 1992). These procedures have been implemented on the water distribution network of Copparo (FE), managed by CADF; the experimentation was developed at a simplified level, applying those approaches which require low accuracy of data (L0 – qualitative, or L1 – quantitative when possible). A specific software has been realized for the elaboration of necessary data and their implementation into the decision support methods.

The urban distribution system at issue, whose data have been derived from the electronic database described above in this paper (see 3.1 for more details), consists of 333 mains for a total length of 138,920 metres. It is worth underlining that, being the available data quite poor, the proposed analysis should be deemed as preliminary, and often relied on classes of parameters rather than punctual values.

The rehabilitation technique considered herein is the Open Cut Replacement – OC; a rehabilitation programme for year 2002 is intended to be the result of the procedures implemented.

A value for the five points of view considered (see 4.2) was calculated for each of the 333 pipes in Copparo, which were then ranked according to a weighted average of the above values. As a result, a score ranging between 0 and 1 was associated to each of the mains (the highest the score, the highest the need for rehabilitation). The first 100 pipes in this ranking were selected for further analysis with Electre tri.

Before its implementation, Electre tri requires some parameters be defined: values were assigned to weights, reference values and thresholds in accordance with literature findings (Mousseau et al., 1999). Electre tri grouped the 100 links analysed into six classes, reported in table 4:

<table>
<thead>
<tr>
<th>Electre tri class</th>
<th>Number of pipes</th>
<th>Rehabilitation need within year 2002</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2</td>
<td>very high</td>
</tr>
<tr>
<td>II</td>
<td>0</td>
<td>high</td>
</tr>
<tr>
<td>III</td>
<td>0</td>
<td>medium - high</td>
</tr>
<tr>
<td>IV</td>
<td>1</td>
<td>medium - low</td>
</tr>
<tr>
<td>V</td>
<td>13</td>
<td>low</td>
</tr>
<tr>
<td>VI</td>
<td>84</td>
<td>very low</td>
</tr>
</tbody>
</table>

A relevant correspondence was found to exist between the Electre tri classes and the real condition of the analysed pipes. The 16 mains ranked by Electre tri as those presenting the [relatively] highest need for rehabilitation (classes I to V) indeed present some common features:

- all of them were laid more than twenty years ago;
- most of them were affected by numerous failures in the last years;
- two of them are situated in an area presenting high population density, high service connection density and frequent overcoming of chemical-physical threshold values for water quality.
BIBLIOGRAPHIC REFERENCES


