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USING ELECTRE TRI TO SUPPORT MAINTENANCE OF WATER DISTRIBUTION NETWORKS

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ABSTRACT. Problems encountered in the context of the maintenance management of water supply are evidenced by the lack of decision support models which gives a manager overview of the system. This paper, therefore, develops a model that uses, in its framework, the multicriteria outranking method ELECTRE TRI. The objective is to sort the areas of water flow measurement of a water distribution network, by priority of maintenance, with data collected from an automated system of abnormalities detection. This sorting is designed to support maintenance decisions in terms of the measure more appropriate to be applied per region. To illustrate the proposed model, an application was performed in a city with 100 thousand water connections. With this model it becomes possible to improve the allocation of maintenance measures for regions and mainly to improve the operation of the distribution network.

Keywords: multicriteria decision making, maintenance management, water supply maintenance.

1 INTRODUCTION

It is noticeable that in some countries, there is deficiency in the management of potable water use by the sanitation companies and it generates undesirable wastage such as: physical and economic losses as well, which are due to, in some cases, the lack of planning on the achievements of the system maintenance. Because of the importance of water supply, natural resource essential to human, is that studies are designed to improve the maintenance actions in distribution networks, with the main objective of reducing the problems of those networks, and therefore, waste.

Lambert & Hirner (2000) showed that water supply systems have, by their nature and complexity, some degree of loss in production and distribution. A major problem highlighted is that water utilities have been living with high levels of losses, mainly by lack of management and appropriate decisions. The result of losses in a supply system for consumers is that there is a reduction of service quality in terms of water availability and pollution problems caused by negative pressures, arising from interruptions in supply, beyond the financial impact on companies.

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These problems usually stand out in medium and large cities and the factors that help to further aggravate them are the population growth; extended periods of drought; the irrational use of water, mainly by the lack of planned maintenance and sometimes even the inadequate operation of treatment systems and distribution, which causes high rates of damage by constant losses in the pipes.

Historically, when there are high losses in the supply system, it becomes more economical to improve, rationalize water use and perform continuous maintenance in order to keep the system efficient, to build new systems, which certainly will lead to high installation costs, plus environmental impact. Issues relating to loss of water must be treated and managed with preventive measures aimed to improve the procedures for maintenance and operation of networks.

Therefore, investments are required by the authorities in conservation programs and efficiency in water use and also the maintenance of distribution networks to reduce losses, but if these investments are not made, the future may be brought into social chaos likely derived from the lack of water. So, in this case the problem is the lack of foresight, decisions, planning and investments by the public sector and the management companies.

On the other hand, make a decision about where and how to act in these situations can be a very complex task because there are a number of difficulties, which consider different criteria that constantly present conflicts among them. Thus, managers responsible for planning and decisions in the sanitation maintenance sector are seeking to integrate available resources with the corporate goals; however in most cases they do not have access to specific models to support decision making and appropriate tools to aid these decisions.

Nevertheless, multicriteria analysis is a technique to structure and analyze complex decisions, which involve multiple criteria, some of them conflicting with each other when evaluating the actions, so the consequences of which have economic, social and environmental impacts (Hajkowicz, 2008). Hajkowicz & Collins (2007) identified eight areas of application of multicriteria analysis in water resources: catchment management; ground water management; infrastructure selection; project appraisal; water allocation; water policy and the planning of supply; water quality management; and marine protected area management. Multicriteria analysis also can provide solutions for complex water decision-making problems (Silva *et al.*, 2010; Morais & Almeida, 2006; Morais & Almeida, 2010). For others recent surveys on the subject, see, Opricovic (2009), Raju & Kumar (2006), and Raju *et al.* (2000).

Many approaches of multicriteria decision making have been developed in order to solve problems inherent to decision making process (Alencar *et al.*, 2010; Alencar & Almeida, 2008; Szajubok *et al.*, 2005). Some models can be specifically related to maintenance management or prioritization of areas to reduce water losses. Morais *et al.* (2010) presented a model based on the PROMETHEE I method for prioritizing critical areas of losses in a city. This approach considered criteria related to technical aspects, water quality and social aspects, which led to the conclusion that although the model has been applied to a small town, fits perfectly to similar problems involving large cities. Damaso & Garcia (2009) presented an approach to the availability of the aging model systems in standby mode, based on the generalized renewal process, to be used to optimize the scheduling of testing and preventive maintenance. As well, the aim of this study is to provide a tactical view on the actions to be implemented, the model of Damaso & Garcia (2009), could be incorporated into a second stage of this work, when the actions are effectively implemented in order to promote a more detailed study for preventive maintenance.

Indeed, in the literature are found few models that specifically address the question of maintenance management on water distribution networks. Furthermore, the models found deals with the problematic of ranking or selection. However, any procedure was found to deal the problem with a sorting problematic. Then, this paper presents a new development with regard to the management and automatic routing of effective maintenance actions which consequently will generate quality improvements, operation and customer satisfaction. These features provide for the maintenance manager in higher quality decisions allocated to address critical maintenance problems that often plague the population directly.

In this context, there are also some difficulties regarding to allocate an adequate maintenance procedure to be implemented in a specific region to maintain the water distribution system, since there are many aspects of assessments and also different goals to be achieved. As stated before, Morais *et al.* (2010) proposed a prioritization of areas in water supply network to help the operational network management. However, the rank achieved by PROMETHEE I was not enough to give an overview of the water distribution network. Hence, this paper presents a multicriteria decision model, which characterizes a new analysis technique in the maintenance management and uses the multicriteria outranking method ELECTRE TRI, in order to support decision making in the field of sanitation maintenance, through sorting regions from water distribution network into classes of maintenance prioritization, and thereby improve the application of maintenance actions, essentially to reduce losses.

Briefly, this paper is organized as follow: Section 2 presents a brief description of the problem of maintenance management and water losses in water supply systems; Section 3 presents the proposed model; Section 4 describes an application of the proposed model in a water distribution network; Section 5 an analysis and evaluation of results is presented, and, finally, Section 6 presents the final remarks.

2 MAINTENANCE MANAGEMENT

An important point to consider, when maintenance is a strategy in business: stop breeding or providing services to clients for losses or undesirable situations may become fatal to the performance and development of a company (Kardec & Carvalho, 2002). The maintenance management has an important role in the success of programs to combat waste and the effectiveness of control techniques and systems management. The activities cannot cease without causing unacceptable losses to the productive process.

Thus the maintenance sometimes gets to have a similar degree of importance to the production. Strategically, the maintenance is not only as an act of planning or performing a corrective action or maintenance of an item, but also decisions on actions planned and scheduled to ensure availability of products or services and the efficiency of the organization against the market and its customers.

Companies that operate in water supply, often perform maintenance on the supply networks in corrective or preventive forms. Maintenance is a constant in this industry, because the carriers pipes break frequently due to many factors: whether for repairs to urban roads, either by increasing on the pressures on these networks or by climatic factors.

Strategic maintenance needs to be applied in a systematic manner through management plans and decisions on programming along with improvements in the supply system; with it companies improve the availability of products and services.

To adopt a policy of work seeking to apply the maintenance effectively, it should be noted two essential points, the first one is about the physical losses and the non-physical (or commercial) and the second, the maintenance alternatives.

The physical losses are the resulting from:

- visible or not visible leaks,
- damaged appliances, poorly maintained or out of its useful life,
- low quality of the hydraulic materials,
- leakage in reservoirs;
- lack of sectors in areas of pressure and maneuver, causing high pressure on the networks, Consequently resulting in disruptions on the pipes, fittings, valves and metering devices that compose the system (Morais *et al.*, 2010).

The not physical losses, or commercial, are cases in which the water arrives the consumer, however illegally, impediment that the values on the consumption have being recorded, causing economic losses for the company and increasing the rate of waste, as these losses are added to the overall index.

The illegal connections, besides the economic loss because they are poorly installed, easily break down and result in an unknown or difficult access leak. As an illustration, Table 1, below, provides some information on losses estimated at several locations in the world:

The maintenance alternatives aimed at conservation and combating water wastage are linked simultaneously to the planning, to the project, to the construction, to the operation and, to the maintenance of systems itself.

However, some difficulties are found in the decision making regarding to the allocation of the most appropriate maintenance processes for each specific region of the water distribution network, especially because there are multiple criteria to be evaluated and often conflicting each other.

Table 1 – Estimated losses of water leaking from pipes in some cities in the world (Water Pages, 2001).

Losses	Location	Source of information
50%	Boston (1977)	U.S. Environmental Protection Agency Office of Water
36%	Boston (recently)	U.S. Environmental Protection Agency Office of Water
81 billion gallons per year	California	U.S. Environmental Protection Agency Office of Water
10-30%	Production Systems in Canada	Environment Agency – Canada
25-30%	Canadian Cities	National Research Council of Canada (1998)
30%	Damasco	Marq de Villiers: "Water", Stoddart Publishing Co. (1999)
40%	Italy	U.S. Water News Online, "Dry Faucets Enrage Italians" (2002)
12,5%	Johannesburg (South Africa)	Open letter of Johannesburg Water (2002)
50%	London	Marq de Villiers: "Water", Stoddart Publishing Co. (1999)
55%	Manila	International Finance Corporation (1997)
32%	Mexico City	Mexico Connect (1999)
40%	Montreal	"More water shortages forecast for communities across nation" by Dennis Bueckert (2004)
10%	New York	U.S. Environmental Protection Agency Office of Water
50%	Cities in Western Norway	—
20%	Ontario	Ontario Sewer and Watermain Construction Association – OSWCA (2001)
50-70%	Norway	"Civil Engeineering Practice", P.N. Cheremisinoff *et al.* Editors, Technomic Publishing Co, Inc., Basel (1988)
35%	Seoul, Korea	Seoul Metropolitan government
> 30%	Ukraine	< www.mama-86.kiev.ua >
3,42 billion gallons per day	England	Weekly Telegraph, August 15-21 (2007)
35-55%	Older systems with poor conditions	A.C. Twort *et al.*: "Water Supply", Fourth Edition, Arnold (1994)

3 PROPOSED DECISION MODEL

The diagram below shows the summary of the model with the perception of the steps. It is possible to visualize the sequencing of steps and tasks that must be completed and efficiency of the proposed application.

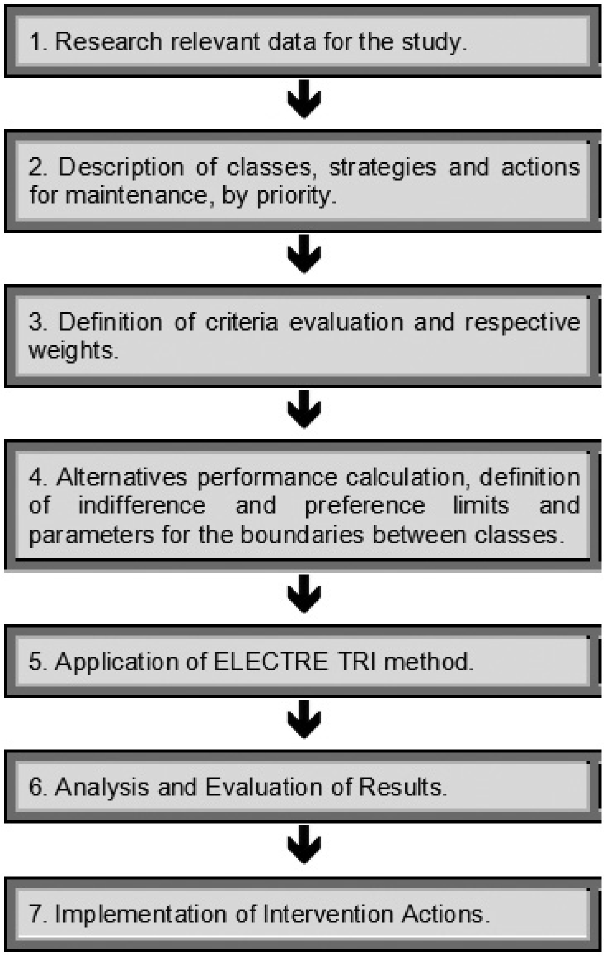

Figure 1 – Diagram of the proposed decision model.

The quantitative models can be characterized because they can be investigated by the techniques of mathematical analysis. The application of these techniques is particularly necessary to obtain somehow a structured decision for the indicated problem. To obtain a quantitative model, all variables must be restricted to be measurable cardinally.

In addition to it, the model must be quite simple so that mathematics can be applied successfully. The choice of the method used depends on the type of problem in examination, of the studied context, the actors involved, the structure of preferences and the type of response that you want to achieve, in other words, what is the reference problem (Gomes *et al.*, 2002).

In many cases, a quantitative model clearly describes only a small section of the real problem which is being investigated. Thus, the quality of a decision often depends on of the quantitative model used.

3.1 The ELECTRE TRI method

The ELECTRE TRI is a multicriteria method that allocates alternatives in predefined categories.

This allocation of an alternative a results from the comparison of a with defined profiles of the limits from the categories (Mousseau & Slowinski, 1998; Yu, 1992).

Given a set of criteria indices $\{g_1, \ldots, g_i, \ldots, g_m\}$ and a set of indices of profiles $\{b_1, \ldots, b_h, \ldots, b_p\}$ are defined $(p+1)$ categories, where b_h represents the upper class and the lower C_h, C_{h+1} category, with $h = 1, 2, \ldots, p$ (Fig. 2).

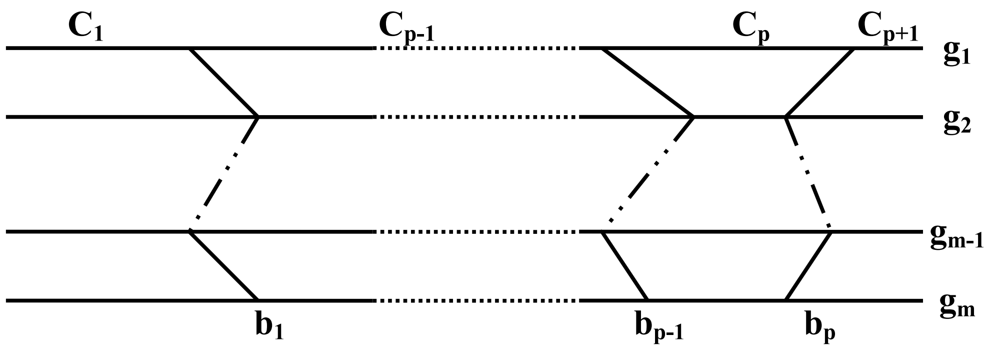

Figure 2 – Boundaries between categories (Mousseau & Slowinski, 1998).

The preferences for each criterion are defined by pseudo criteria in which the preference thresholds and indifference $p_j[g(b_h)]$ and $q_j[g(b_h)]$ provide intra criteria information. Thus, $q_j[g(b_h)]$ specifies the largest difference $g_j(a) - g_j(b_h)$, which preserves the indifference between a and b_h in the criteria g_j and $p_j[g(b_h)]$ representing the smallest difference $g_j(a) - g_j(b_h)$, consistent with a preference for a in the criteria g_j. The structure preferably with pseudo criteria - double threshold model with $p_j[g(b_h)]$ and $q_j[g(b_h)]$, avoids an abrupt transition between indifference and strict preference, existing a zone of hesitation, represented by the weak preference. The ELECTRE TRI constructs outranking relations S, it means, it validates or invalidates the assertion that aSb_h and (b_hSa), whose meaning is "a is at least as good as b_h".

Two conditions must be verified to validate the assertion aSb_h:

- **Concordance:** For an outranking aSb_h to be accepted, most of the criteria should be in favor of affirming aSb_h.
- **Non-discordance:** when in concordance condition is not satisfied, none of the criteria should be opposed to the assertion aSb_h.

In the construction of S it is used a set of veto thresholds $[v_1(b_h), v_2(b_h), \ldots, v_m(b_h)]$, used in the test of inconsistency $v_j(b_h)$, which represents the smallest difference $g_j(b_h) - g_j(a)$

inconsistent with the statement aSb_h. The indexes of partial concordance $c_j(a, b)$, concordance $c(a, b)$ and partial discordance $d_j(a, b)$ are calculated by the expressions (1), (2) and (3) below.

$$c_j(a,b) = \begin{cases} 0 & \text{if} \quad g_j(b_h) - g_j(a) \geq p_j(b_h) \\ 1 & \text{if} \quad g_j(b_h) - g_j(a) \leq q_j(b_h) \\ & \dfrac{p_j(b_h) + g_j(a) - g_j(b_h)}{p_j(b_h) - q_j(b_h)}, \text{otherwise} \end{cases} \tag{1}$$

$$c(a,b) = \frac{\sum\limits_{j \in F} k_j c_j(a, b_h)}{\sum\limits_{j \in F} k_j} \tag{2}$$

$$d_j(a,b) = \begin{cases} 0 & \text{if} \quad g_j(b_h) - g_j(a) \leq p_j(b_h) \\ 1 & \text{if} \quad g_j(b_h) - g_j(a) > v_j(b_h) \\ & \dfrac{g_j(b_h) + g_j(a) - p_j(b_h)}{v_j(b_h) - p_j(b_h)}, \text{otherwise} \end{cases} \tag{3}$$

The ELECTRE TRI constructs an index $\sigma(a, b_h) \in [0, 1]$ ($\sigma(b_h, a)$, respectively) which represents the degree of credibility of the assertion in which aSb_h, $a \in A$, $h \in B$, expression (4).

The statement aSb_h is considered valid if $\sigma(a, b_h) \geq \lambda \cdot \lambda$ starts a cutoff level such that $\lambda \in [0, 5, 1]$ (Mousseau *et al.*, 2001).

$$\sigma(a, b_h) = c(a, b_h) \cdot \prod_{j \in F} \frac{1 - d_j(a, b_h)}{1 - c(a, b_h)} \tag{4}$$

where, $\overline{F} = \{ j \in F : d_j(a, b_h) > c_j(a, b_h) \}$

After calculating the indices $\rho(k, b_h)$ and $\rho(b_h, k)$, we use a cut off level $\lambda \in [0.5, 1]$ to determine the preferably relationship with the condition: $\rho(k, b_h) \geq \lambda \Rightarrow a_k S b_h$. Thus, the higher the value of λ, the more severe are the subordination conditions of one alternative over the border. So with ELECTRE TRI, mainly used in alternative classification problems, it seeks to assign the performance of the alternatives in one of the of predefined performance classes.

Two assignment procedures can be evaluated: Pessimistic procedure and Optimistic procedure (Mousseau *et al.*, 2001).

- **Pessimistic procedure:** compares successively with b_i, to $i = p, p-1, \ldots, 0, b_h$, starting with the first profile such in which aSb_h says to the category $C_{h+1}(a \rightarrow C_{h+1})$.
- **Optimistic procedure:** compares successively with b_i, to $i = 1, 2, \ldots, p, b_h$, starting with the first profile, such that "b_h is preferable to a" says C_h for category $(a \rightarrow C_h)$.

The b_h is the first threshold value such in which $a_k S b_h$ assigns the alternative a_k to class C_{h+1}. If the values of b_h and b_{h-1} are the lower and upper limits from class C_h, this procedure gives to a_k the highest class C_h, such in which a_k makes the value $b_{h-1}(a_k S b_{h-1})$.

Moreover, the optimistic procedure compares the performance of a_k successively to b_i, $i = 1, 2, \ldots, p$. Being b_h the threshold value such in which $b_h P a_k$, must assign a_k to the class C_h. This procedure assigns to a_k the class C_h , but lower, in which the upper limit b_h is preferred to $a_k(b_h P a_k)$. The description and understanding of the ELECTRE TRI sorting algorithm requires an additional effort, especially by the fact that this method is based on recent concepts of fuzzy logic.

Nevertheless, understanding and modeling by the ELECTRE TRI dispense the detailed description of the classification algorithm (Costa & Freitas, 2005).

3.2 Inference model of the ELECTRE TRI

While using the ELECTRE TRI, one of the greatest difficulties of the analyst is when he interacts with the decision maker to elicit the various parameters of preferences. The analyst must determine the values of various parameters (the profiles that define the boundaries between categories, weights, thresholds ...), which are used to construct a model from the decision maker's preference. Even if these parameters can be interpreted, it is difficult to attach values to them directly and have a clear global understanding of the implications that these values have for the model output. Except in some specific cases, it is not natural to assume that the decision maker can explicitly assign values to these parameters, since they are different from the natural terms to the decision maker expresses his preferences.

Mousseau & Slowinski (1998) proposed a model to infer in the parameters of the ELECTRE TRI to an analysis of the examples given by the decision maker, in other words, the holistic judgments. This approach represents the disintegration paradigm of the preferences in which aims to extract the implicit information contained in the holistic judgments given by a decision maker. The aim of this approach is to find an ELECTRE TRI model compatible with the examples given by the decision maker. The examples given relate to a subset $A^* \in A$ to alternatives for which the decision maker has clear preferences, that is alternatives where the decision maker can easily specify a category, taking into consideration his ratings for all criteria. The compatibility between the model of the ELECTRE TRI and examples of the assignment is understood as an ability of the ELECTRE TRI method using the inference model to reassign the alternatives from A^* in the same way that the decision maker did.

4 APPLICATION IN A WATER DISTRIBUTION NETWORK

This application has the purpose to analyze the proposed decision model in a situation with relative number of regions (alternatives) to sort into classes of maintenance procedures, evaluating about some criteria. The proposed model was applied in a medium sized town (approximately

450,000 inhabitants), which serves 100,000 active water connections, data collected from a public utility water supply.

The situation of the maintenance on the distribution network at the time of data collection can be viewed by the information about losses and volume in each region of measurement.

At first, it is verified what strategies or actions could be employed to achieve the objectives separately and some alternatives that can generate the expected result for the goals. These actions are listed based on statistical data system and experience of the decision maker, such as registration information, delivered or distributed volumes (total volume from water available in the distribution networks from a city) and Macromedia (the sum from the volumes measured in each consumer unit), information equipment useful life, when maintenance or replacement should occur, areas with higher rates of leakage and assistance, information on administrative and financial conditions, information on the level of automation of the system, raising the pressure on networks etc.

In this study, we used data from a specialized monitoring system (SMS) (Trojan & Marçal, 2007). This monitoring system was based on theories of artificial intelligence and provides the flow monitoring of measured areas.

The Figure 3 shows how the system makes the data collection, which will be used to implement the decision support method ELECTRE TRI.

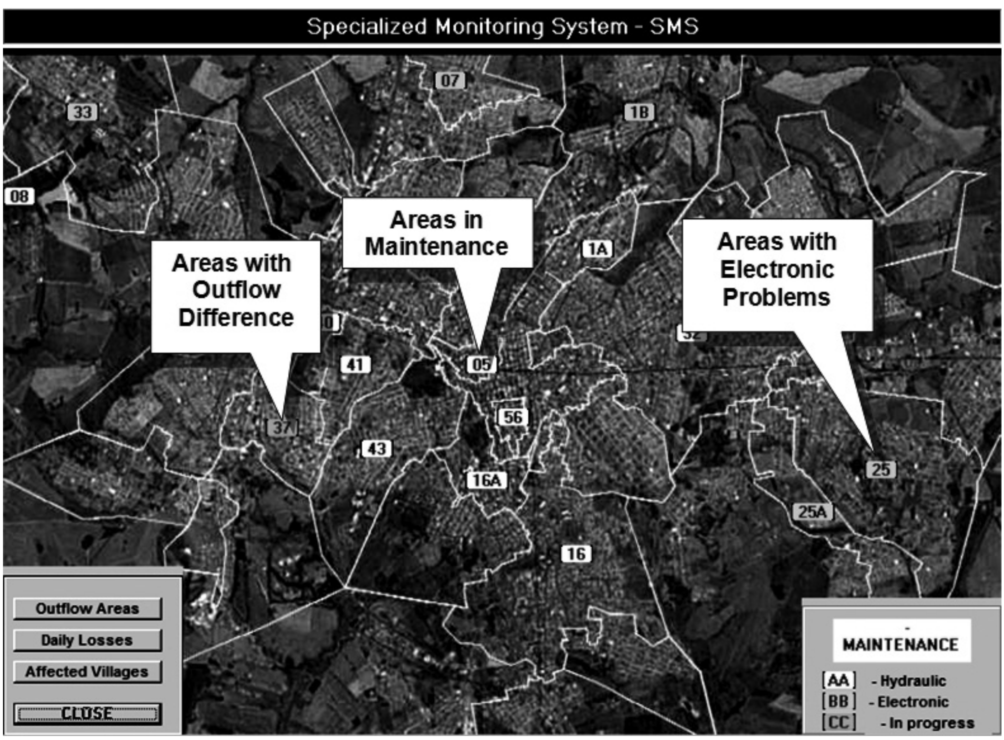

Figure 3 – Specialized Monitoring System, SMS.

Table 2 presents a survey of relevant data generated by the SMS. These data were listed per alternative (areas of flow measurement). The areas of flow measurement were divided according to geographical features and extensions for power main line of supply.

Table 2 – Data from the study.

a_n	Area *(name)*	Connections *(unit)*	Produced *(m^3/month)*	Measured *(m^3/month)*	Losses *(%)*	Networks *(m/conn.)*	Consumption *(l/hab/day)*	Economies *(unit)*	Population *(inhabitants)*
a_1	01FT06	743	16,950	10,252	39.52	13.80	133.96	757	2,551
a_2	01FT08	2,738	76,105	41,232	37.31	15.06	109.21	3,734	12,584
a_3	07FT01	1,556	22,044	15,810	28.28	9.70	96.82	1,615	5,443
a_4	08FT01	1,102	28,352	13,892	51.00	12.68	129.02	1,065	3,589
a_5	11FT01	1,003	14,632	9,442	35.47	8.49	92.18	1,013	3,414
a_6	15FT01	2,341	38,531	24,975	35.18	11.41	96.83	2,551	8,597
a_7	16FT01	12,092	314,993	149,243	52.62	12.02	122.08	12,092	40,750
a_8	18FT01	2,857	53,044	27,223	48.68	9.53	93.20	2,889	9,736
a_9	18FT02	2,206	72,451	27,420	62.15	12.43	122.94	2,206	7,434
a_{10}	19FT01	2,337	58,352	26,244	49.30	10.80	102.36	2,536	8,546
a_{11}	25FT01	2,764	60,775	29,208	37.74	11.14	98.50	2,933	9,884
a_{12}	25FT02	1,857	29,043	16,845	42.00	9.46	87.28	1,909	6,433
a_{13}	26FT01	2,804	48,475	29,317	39.52	10.02	100.82	2,876	9,692
a_{14}	27FT01	2,259	34,789	21,901	37.05	9.69	93.73	2,311	7,788
a_{15}	32FT01	19,746	370,917	210,017	32.50	11.75	99.59	20,858	70,291
a_{16}	33FT01	1,540	50,631	18,572	63.32	11.66	118.21	1,554	5,237
a_{17}	36FT01	7,290	138,517	76,603	44.70	10.25	101.56	7,460	25,140
a_{18}	36FT02	4,310	64,128	44,148	31.16	10.25	101.31	4,310	14,525
a_{19}	37FT01	1,434	38,559	15,908	58.74	10.75	107.18	1,468	4,947
a_{20}	39FT01	727	16,064	8,978	44.11	10.98	115.63	768	2,588
a_{21}	39FT02	819	19,766	7,569	61.71	9.51	91.18	821	2,767
a_{22}	40FT01	612	16,982	6,185	63.58	9.86	97.24	629	2,120
a_{23}	41FT01	1,551	34,320	16,646	51.50	10.56	103.67	1,588	5,352
a_{24}	43FT01	2,491	76,668	28,693	62.57	11.25	107.22	2,647	8,920
a_{25}	49FT01	3,858	67,710	42,315	37.51	9.94	106.60	3,926	13,231
a_{26}	64FT01	1,814	40,704	30,033	26.21	15.94	131.15	2,265	7,633
a_{27}	68FT01	3,808	144,400	41,519	71.25	10.90	105.84	3,880	13,076
a_{28}	73FT01	1,578	29,574	10,133	35.30	11.47	114.47	1,653	5,571
a_{29}	74FT01	3,912	92,920	46,523	49.93	11.41	113.16	4,066	13,703
a_{30}	74FT02	2,334	63,346	27,390	56.76	11.37	112.27	2,413	8,132

At the entrance and in some cases within each defined area were installed electromagnetic flow meters which indicate the flow consumption of each one of them. This way it is possible to raise the number of connections, population, network meters and public economies, since these areas are large areas defined and tight.

To each one of them was assigned a name of reference represented by the tag: "area number + the indication FT (flow transmitter) + the number of the measure." For example: 01FT06 = Area 01 + FT + 06 measurer.

After data collection it is necessary to elicit about the characteristics needed for the classes and the maintenance actions that can be performed on alternate view to see to which class this alternative belongs.

These characteristics are listed based on the subjectivity of the decision maker when it comes to the relevant points for each criterion.

Thus, as Table 3, it is possible to reach a delimitation of maintenance actions required in each class, number of classes and their priorities as well as the appropriate moment for the intervention.

In this context were defined five classes with priorities: Very High, High, Moderate, Low and Very Low. Each one with its respective intervention programs and required actions.

Table 3 – Description of classes by priority, strategies and actions for maintenance.

Classes	Priority	Intervention	Actions needed
C_1	Very high	Immediate	Continuous Geophone, continuous sectorization, P.M.;
C_2	High	Moderate high	Studies on flow rates and pressures, Periodic Geophone, P.M.;
C_3	Moderate	Moderate low	Seasonal Geophone, Sectorization of maneuvering and pressure, C.M.;
C_4	Low	Regular	Monitoring of pressure and flow in networks, C.M.;
C_5	Very low	Low	Checking in sectors maneuver, C.M.

C.M. → Corrective Maintenance; P.M. → Preventive Maintenance.

The next step then is to define the criteria that will lead to the alternatives to over-process. In this study, six criteria were needed to represent the situation where each alternative would be positioned and then apply the method ELECTRE TRI. The criteria listed define a study on the number of connections, loss index, and measured volumes for each one of the areas in question and also the indicator of meters per net connection, that helps in the perception of populated regions, such as apartment buildings and condominiums. Still it will be considered in the criteria 6, the location of buildings intended to public use, such as hospitals, kindergartens, schools and government buildings. Table 4 provides the information described in this paragraph.

Table 4 – Definition of criteria evaluation and respective weights.

Criteria	Weights	Attributes
g_1	0.23	Number of water connections
g_2	0.15	Percentage of losses
g_3	0.15	Population
g_4	0.15	Volume measured
g_5	0.12	Network meters per water connections
g_6	0.20	Number of public economies

The weights of the criteria were obtained through an elicitation process with the decision maker involved in the maintenance of water networks, in order to present the importance of each criterion is the vision for the analysis of the decision maker. Was considered a range [000-100] to define the alternatives performance and the occurrence of a situation within from the items considered in each criterion receives a percentage value relative to the number of items listed to examination. Only the criterion g_2 has the characteristic of minimizing the others are maximizing. Subsequently each criterion will have an aggregated performance and this result should be taken for the calculation of concordance and non-discordance. The considerations on thresholds of indifference and preference should be defined at this stage with the purpose of allowing small variations that are covered by these thresholds. To calculate the performance of the alternatives it was considered the withdrawal amount for each alternative in relation to the average or the maximum number of sample to the considered criteria.

When a value exceeds the average value it is assigned 100 and below the average values are represented by a relation between the average values and multiplied by 100 to calculate the value referring to the performance of the alternative against the analyzed criteria. On the criteria: losses, networks and public economist were considered the maximum value instead of the average as a relevant threshold to the calculation. Tables 5, 6 and 7 below show the development of the above steps.

The parameters that define the regions boundaries between classes are defined in this step, as shown in Table 7.

Briefly, the limit of indifference q_j specifies the largest difference between the value of alternative a_k (denoted by $g_j(a_k)$) and the standard value of a boundary b_h (denoted by $g_j(b_h)$) that preserves indifference between a_k and $b_h(a_k I_j b_h)$. Moreover, the preference limit of p_j specifies the smallest difference between the value of alternative a_k denoted by $g_j(a_k)$ and the default standard value of a border b_h (denoted by $g_j(b_h)$) establishing the strong preference between $a_k, b_h(a_k P_j b_h)$. The relation $a_k Q_j b_h$ represents an intermediate situation of hesitation between indifference and preference, called weak preference. The set of expressions (5) describes these relationships, but only one of them can occur.

$$\begin{cases} a_k I_j b_h \Leftrightarrow |g(a_k) - g(b_h)| \leq q_j \\ a_k Q_j b_h \Leftrightarrow g(b_h) + p_j \geq g(a_k) > g(b_h) + q_j \\ a_k P_j b_h \Leftrightarrow |g(a_k) - g(b_h)| > p_j \end{cases} \tag{5}$$

Table 5 – Alternatives performance – calculation.

a_n	Area (name)	Connec. (unit.)	Connec. average	Produced (m^3/month)	Measured (m^3/month)	Meas./ average	Losses (%)	Losses/ max.	Net. m/conn.	Net./ max.	Cons. l/hab/day	Econ. (unit)	Popul. (inhab.)	Popul./ average
a_1	01FT06	743	23	16,950	10,252	29	39.52	55	13.80	87	133.96	757	2,551	23
a_2	01FT08	2,738	85	76,105	41,232	100	37.31	52	15.06	94	109.21	3,734	12,584	100
a_3	07FT01	1,556	48	22,044	15,810	44	28.28	40	9.70	61	96.82	1,615	5,443	48
a_4	08FT01	1,102	34	28,352	13,892	39	51.00	72	12.68	80	129.02	1,065	3,589	32
a_5	11FT01	1,003	31	14,632	9,442	26	35.47	50	8.49	53	92.18	1,013	3,414	30
a_6	15FT01	2,341	73	38,531	24,975	70	35.18	49	11.41	72	96.83	2,551	8,597	76
a_7	16FT01	12,092	100	314,993	149,243	100	52.62	74	12.02	75	122.08	12,092	40,750	100
a_8	18FT01	2,857	89	53,044	27,223	76	48.68	68	9.53	60	93.20	2,889	9,736	86
a_9	18FT02	2,206	69	72,451	27,420	77	62.15	87	12.43	78	122.94	2,206	7,434	66
a_{10}	19FT01	2,337	73	58,352	26,244	73	49.3	69	10.8	68	102.36	2,536	8,546	75
a_{11}	25FT01	2,764	86	60,775	29,208	82	37.74	53	11.14	70	98.50	2,933	9,884	87
a_{12}	25FT02	1,857	58	29,043	16,845	47	42.00	59	9.46	59	87.28	1,909	6,433	57
a_{13}	26FT01	2,804	87	48,475	29,317	82	39.52	55	10.02	63	100.82	2,876	9,692	86
a_{14}	27FT01	2,259	70	34,789	21,901	61	37.05	52	9.69	61	93.73	2,311	7,788	69
a_{15}	32FT01	19,746	100	370,917	210,017	100	32.50	46	11.75	74	99.59	20,858	70,291	100
a_{16}	33FT01	1,540	48	50,631	18,572	52	63.32	89	11.66	73	118.21	1,554	5,237	46
a_{17}	36FT01	7,290	100	138,517	76,603	100	44.70	63	10.25	64	101.56	7,460	25,140	100
a_{18}	36FT02	4,310	100	64,128	44,148	100	31.16	44	10.25	64	101.31	4,310	14,525	100
a_{19}	37FT01	1,434	45	38,559	15,908	44	58.74	82	10.75	67	107.18	1,468	4,947	44
a_{20}	39FT01	727	23	16,064	8,978	25	44.11	62	10.98	69	115.63	768	2,588	23
a_{21}	39FT02	819	25	19,766	7,569	21	61.71	87	9.51	60	91.18	821	2,767	24
a_{22}	40FT01	612	19	16,982	6,185	17	63.58	89	9.86	62	97.24	629	2,120	19
a_{23}	41FT01	1,551	48	34,320	16,646	46	51.50	72	10.56	66	103.67	1,588	5,352	47
a_{24}	43FT01	2,491	77	76,668	28,693	80	62.57	88	11.25	71	107.22	2,647	8,920	79
a_{25}	49FT01	3,858	100	67,710	42,315	100	37.51	53	9.94	62	106.60	3,926	13,231	100
a_{26}	64FT01	1,814	56	40,704	30,033	84	26.21	37	15.94	100	131.15	2,265	7,633	67
a_{27}	68FT01	3,808	100	144,400	41,519	100	71.25	100	10.90	68	105.84	3,880	13,076	100
a_{28}	73FT01	1,578	49	29,574	10,133	28	35.30	50	11.47	72	114.47	1,653	5,571	49
a_{29}	74FT01	3,912	100	92,920	46,523	100	49.93	70	11.41	72	113.16	4,066	13,703	100
a_{30}	74FT02	2,334	73	63,346	27,390	76	56.76	80	11.37	71	112.27	2,413	8,132	72
		3,216 average			35,808 average		71 max.		16 max.				11,322 average	

Table 6 – Alternatives performance – values.

Area	Connections g_1	Losses g_2	Popul. g_3	Measured g_4	Nets g_5	Public econ. g_6
a_1 – 01FT06	23	29	55	87	23	50
a_2 – 01FT08	85	100	52	94	100	25
a_3 – 07FT01	48	44	40	61	48	25
a_4 – 08FT01	34	39	72	80	32	10
a_5 – 11FT01	31	26	50	53	30	10
a_6 – 15FT01	73	70	49	72	76	25
a_7 – 16FT01	100	100	74	75	100	100
a_8 – 18FT01	89	76	68	60	86	30
a_9 – 18FT02	69	77	87	78	66	25
a_{10} – 19FT01	73	73	69	68	75	25
a_{11} – 25FT01	86	82	53	70	87	35
a_{12} – 25FT02	58	47	59	59	57	15
a_{13} – 26FT01	87	82	55	63	86	100
a_{14} – 27FT01	70	61	52	61	69	100
a_{15} – 32FT01	100	100	46	74	100	50
a_{16} – 33FT01	48	52	89	73	46	15
a_{17} – 36FT01	100	100	63	64	100	50
a_{18} – 36FT02	100	100	44	64	100	30
a_{19} – 37FT01	45	44	82	67	44	25
a_{20} – 39FT01	23	25	62	69	23	25
a_{21} – 39FT02	25	21	87	60	24	25
a_{22} – 40FT01	19	17	89	62	19	15
a_{23} – 41FT01	48	46	72	66	47	25
a_{24} – 43FT01	77	80	88	71	79	15
a_{25} – 49FT01	100	100	53	62	100	20
a_{26} – 64FT01	56	84	37	100	67	20
a_{27} – 68FT01	100	100	100	68	100	25
a_{28} – 73FT01	49	28	50	72	49	20
a_{29} – 74FT01	100	100	70	72	100	45
a_{30} – 74FT02	73	76	80	71	72	40

Table 7 – Parameters for the boundaries between classes.

Classes	Priority	Border	g_1	g_2	g_3	g_4	g_5	g_6
C_1	Very high	b_1	90	80	90	90	10	90
C_2	High	b_2	65	55	65	60	30	70
C_3	Moderate	b_3	45	40	40	40	55	50
C_4	Low	b_4	25	20	20	10	70	20
C_5	Very low	–	–	–	–	–	–	–

Illustratively, to demonstrate the steps of calculation the ELECTRE TRI method, are considered, analyzed from the g_4 criteria, the value of alternative a_8, the standard value of b_2 border, the indifference limit and the preference limit denoted respectively by: $(a_8) = 60$, $g_4(b_2) = 60$; $q_4 = 4$ and $p_4 = 8$. Considering the above mentioned relations and their values, it is concluded that the alternative a_8 is preferable to the border $b_2(a_8 P_4 b_2)$ analyzed from the g_4 criteria. Similar procedure can be performed for the other the criteria, alternatives and borders.

$$a_8 I_4 b_2 = |60 - 60| \leq 4, \quad \text{True}$$

$$a_8 Q_4 b_2 = 60 + 8 \geq 60 > 60 + 4, \quad \text{False}$$

$$a_8 P_4 b_2 = |60 - 60| > 8, \quad \text{False}$$

Thus, the alternative a_8 being analyzed from the g_4 criteria is Indifferent to the limits of class $g_4(b_2)$ and consequently may be included in this class to calculation done with other criteria confirming this trend. To the allocation of alternatives to the categories of classification, it was considered in this experiment, the cut off level $\lambda = 0.76$, a value that gives intermediate level of strictness to examination (for $\lambda \in [0.5, 1]$). With the tabulated data and information elicited from the next step it is summarized in the application of the ELECTRE TRI method for measuring the results of the classification of areas.

The following diagram (Fig. 4) shows the results that this study, finally presenting the classification according to the criteria listed and possible alternatives. To the application of ELECTRE TRI it was used the software ELECTRE TRI 2.0a, available in Lamsade (Paris-Dauphine University, Paris, France).

The Figure 5 summarizes the study of the comparison, identifying the situations of incomparability and Figure 4 shows the results of the alternatives, which facilitates the analysis of the points of action by the recognition of the characteristics.

The names in question represent areas of flow measurement for the classification number (area code + FT (flow transmitter) number of measuring equipment).

On Table 8 it is possible to visualize the statistical results of the study, presented in percentages of occurrences in each class.

Table 8 – Statistics.

Classes	Priority	PESSIMISTIC placement	OPTIMISTIC placement
C_1	Very high	0% (0 of 30)	23% (7 of 30)
C_2	High	3% (1 of 30)	50% (15 of 30)
C_3	Moderate	37% (11 of 30)	27% (8 of 30)
C_4	Low	60% (18 of 30)	0% (0 of 30)
C_5	Very low	0% (0 of 30)	0% (0 of 30)

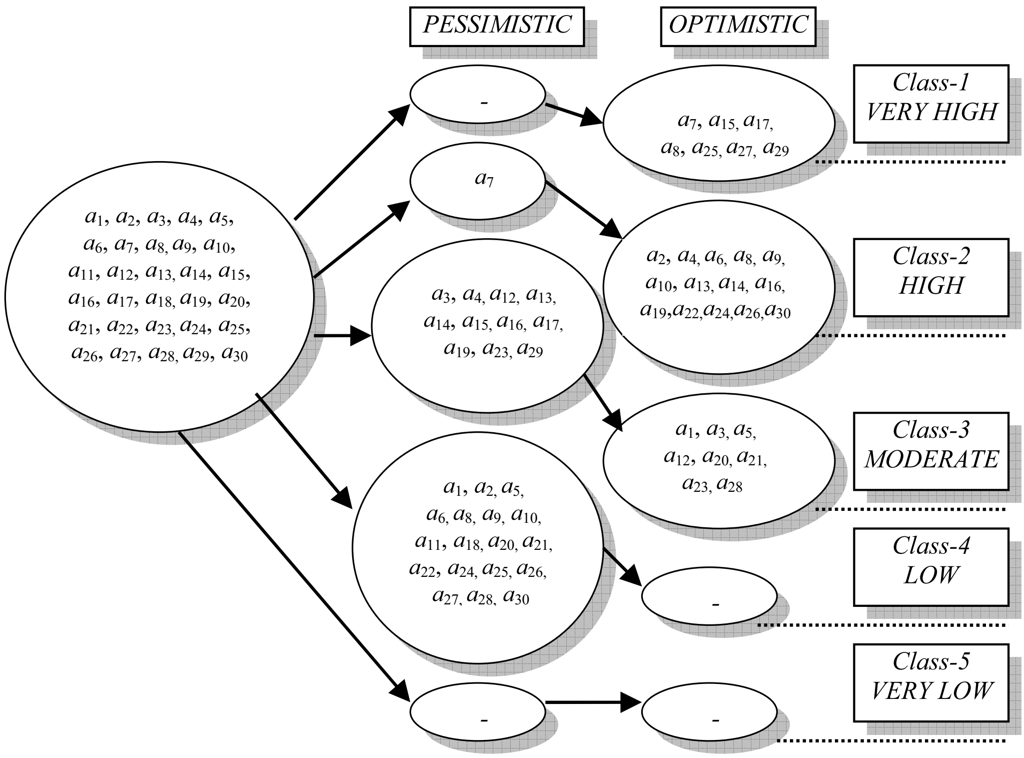

Figure 4 – Classification Results by ELECTRE TRI.

5 ANALYSIS AND EVALUATION OF RESULTS

The results presented in the study, arising from the implementation of proposed model show a logical situation with some preferential areas positioned in the higher classes of the Classification and allocated most of the alternatives on the intermediate classes, which denotes a certain balance in the maintenance system. Thus actions can be focused on priority events and the constant evolution on the middle classes.

The optimistic procedure was adopted, because the optimistic (or disjunctive) assigns a to the lowest category C_h for which the upper profile b_h is preferred to a. When using this procedure with $l = 1$, an alternative a can be assigned to category C_h when $g_j(b_h)$ exceeds $g_j(a)$ (by some threshold) at least for one criterion (disjunctive rule).

Highest class, for example, where the alternatives were ranked in need of immediate intervention emerged alternative a_7, which if analyzed by Table 6 shows the relevant characteristics of the criteria $g_1 = 100$, $g_2 = 100$; $g_5 = 100$ and $g_6 = 100$, which have the largest weights defined for classification. This indicates a preference to attend the higher priority classes.

The fact that most of the classes remained concentrated on the classes with lower priorities or median indicates the necessity of more structured planning and actions to resolve outstanding problems in distribution networks. Also, the lower classes show some consistency, because the

Comparison to Profile

	Pr04	Pr03	Pr02	Pr01
A0001	>	R	<	<
A0002	>	R	R	<
A0003	>	I	<	<
A0004	>	>	R	<
A0005	>	R	<	<
A0006	>	R	R	<
A0007	>	>	>	R
A0008	>	R	R	<
A0009	>	R	R	<
A0010	>	R	R	<
A0011	>	R	R	<
A0012	>	>	<	<
A0013	>	>	R	<
A0014	>	>	R	<
A0015	>	>	R	R
A0016	>	>	R	<
A0017	>	>	R	R
A0018	>	R	R	R
A0019	>	>	R	<
A0020	>	R	<	<
A0021	>	R	<	<
A0022	>	R	R	<
A0023	>	>	<	<
A0024	>	R	R	<
A0025	>	R	R	R
A0026	>	R	R	<
A0027	>	R	R	R
A0028	>	R	<	<
A0029	>	>	R	R
A0030	>	R	R	<

Figure 5 – Comparisons summary.

areas allocated in these classes have the lower performance criteria with higher weights. This rating indicates that these areas may be irrelevant from the perspective of prioritizing interventions, but they require long-term planning.

When analyzing the results of classification model it is possible to notice the delimitation, with concentrations of the important areas, the views of priorities and weights in relation to what the decision maker has set as preferred. The other areas with indifference or incomparability in relation to the classes that they belong to are naturally classified according the performance in the different criteria.

Some incomparabilities can be detected when the alternatives cannot be analyzed, since the criteria that defines the comparison does not show any outranking for those parameters or preferences listed by the decision maker.

6 FINAL REMARKS

The proposed model reached relevant results in a complex situation of maintenance water distribution network, in which multiple objectives are involved. This model can certainly support the decision to sort regions of water network in classes of maintenance priority, allowing reducing problems in public water supply, such as: loss, execution of maintenance actions, deployment automation, monitoring, among others. With this view it is more comfortable to make decisions, as there is the tendency for goals to be met in a more appropriate way.

The model actually allows the immediate visualization of priority classes and maintenance sector of the water distribution networks and uses this information to act quickly in situations that need to meet the priorities of maintenance. The results found in application shown that the areas classified met expectations with some minor variations.

The fact of making the preliminary classification of the priorities sector participation expedites maintenance immediately after the occurrence of leaks or situations that require immediate maintenance on the most important areas from the perspective of the decision maker's preferences.

This study provides the application and horizons of performance to the maintenance management systems in public water supplies.

Therefore this work complies with the goal of building a classification model of priority alternatives with quantitative aspects at the same time to assist in decision making on maintenance of distribution networks in a system of public water supply.

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