Effect of criteria weighting methods on the ranking of water suppliers' performance

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Abstract: - Water supply systems are a structural part of public utilities and as such are vital to the general well-being, public health, safe drinking water use, economic activities and environment protection. Being the water "market" a natural monopoly, regulation must, mainly, protect the interests of the user, based on a benchmarking strategy that promotes the quality of the water supply service and assuring the balance of the ruling tariffs.
Due to the complexity of service quality assessment, the use of performance indicators is essential as a means to provide a measure the utility's effectiveness and efficiency. In Portugal, this task is conducted by an independent public entity, which has defined a specific set of performance indicators. Currently, the adopted system does not provide a quantitative and integrated evaluation leading to an overall ranking of utilities' performance and sustainability.
This work aims to contribute to the improvement of the Portuguese assessment system, through the development of a complementary methodology that defines a *global index of service quality* (GISEQ) for a given water supply utility, based on a new application of multicriteria analysis. The GISEQ value is calculated as a combination of the normalized scores of each performance indicator, previously aggregated in three main groups: protection of user interests, sustainability of the utility and environmental sustainability. In this proposed methodology, each one of the selected performance indicators represents a criterion to be considered and judiciously weighted. An innovative approach to weights definition was performed as well as a sensitivity analysis of different weighting methods on water supply utilities' ranking positions.

Key-Words: - Water supply systems; performance indicators; multicriteria analysis; weighting methods; service quality index (GISEQ).

1 Introduction

Regulation is a tool that aims at reproducing, in a natural monopoly market, the results usually expected in a competitive market.
The principal objective of regulation is to protect the interests of users by fostering quality in the services provided by utilities and ensuring a fair balance in the charges levied, guaranteeing the essentiality, equity, indispensability, feasibility and cost-effectiveness principles [1].
Users' interests are best served by an appropriate investment policy that is the key to ensuring long term continuity of the service and maintenance of service levels. Therefore, it must take into account the need to safeguard the economic viability and the legitimate interests of utilities by ensuring the proper remuneration of invested capital irrespective of its nature (public or private, municipal or multimunicipal), while also safeguarding the environment and contributing to the implementation of governmental policies.
The regulatory action must incorporate the utilities' economic and service quality assessment based on a benchmarking strategy and its public divulging.
The regulation of service quality is a means of controlling behaviours that is inseparable from economic regulation and that influences the behaviours permitted to utilities in terms of the quality of the service they provide to users.
The use of performance indicators is widely recommended as a measure of the utility's effectiveness and efficiency related to specific issues of the activity developed or to the system behaviour.
The indicators translate the performance levels actually obtained and make the comparison between the management objectives and the obtained results a clear and transparent one.

In Portugal, the regulation task is conducted by IRAR (Portuguese Institute for the Regulation of Water and Waste), which has decided to define its own set of performance indicators, which is less comprehensive than those adopted by the IWA (International Water Association).
The IRAR's performance assessment system [2] – applicable to water supply services – is a tool comprised by twenty performance indicators, judiciously selected, which have been analysed in an extended way since 2005 [3]. The use of such performance assessment tools enables the comparison of results between similar utilities (*benchmarking*). However, its implementation entangles carefully set procedures such as data supply by the utilities, data validation, data processing and results interpretation by IRAR for every utility (and the further interpretation for the whole universe of utilities) and the publication and divulging of all this information on a yearly basis, by the publication of a *Performance Assessment Annual Report* [4-7]. With this procedure, each utility knows the evolution over time of the different issues of its own management and the comparison with other similar utilities, with a view to settle the references which enable the setting up of new efficiency targets in a realistic way [1].
Currently, IRAR's system only performs a qualitative assessment of the utility's performance – "unsatisfactory", "medium" or "good" – for each indicator, but not an integrated evaluation that allows establishing an overall ranking of utilities, which could stimulate a continuous improvement of performance, sustainability and quality of the water supply services.
Research work was has been carried out in order to perform this new application of multicriteria analysis and evaluation methodologies, usually applied in Decision Support Systems (DSS) in Regional and Urban Planning processes.
The aim of this paper is to contribute for the improvement of the Portuguese performance weighted, based on the results of an on-line questionnaire proposed to a selected set of academic and professional experts.
The GISEQ values are calculated as a weighted linear combination of the normalized scores of each performance indicator, which is one of the most common aggregation procedures available in the context of multicriteria evaluation [8, 9].
An innovative approach to weights definition was also performed as well as a sensitivity analysis of GISEQ values to different weighting methods.

2 Methods

The methodology used in this work for evaluating service quality of water supply utilities was based upon the development and application of a multicriteria analysis model that in order to obtain service quality indices, global and sectoral.
These indices are used to quantitatively evaluate the performance of each water supplier, enabling the possibility of establishing a general ranking order for different analytical scenarios defined as a function of year, indicator weighting method and universe of comparison.
For this propose, a hierarchical structure was defined based precisely on the referred IRAR's performance assessment system (Table 1), aiming to use the data sets published by IRAR as the scores of the criteria (performance indicators) presented by each water supply utility.

Table 1: The IRAR's Performance Indicators System for water supply services

PROTECTION OF THE USER INTERESTS (I_1)
User service accessibility
AA 01 - Service coverage
AA 02 - Average water charges
Quality of service supplied to users
AA 03 - Service interruptions
AA 04 - Water tests performed
AA 05 - Quality of supplied water
AA 06 - Answers to written complaints
SUSTAINABILITY OF THE UTILITY (I_2)
Utility's economical and financial sustainability
AA 07 - Operating cost coverage ratio
AA 08 - Unit running costs
AA 09 - Solvency ratio
AA 10 - Non-invoiced water
Utility's infrastructural sustainability
AA 11 - Fulfilment of the water intake licensing
AA 12 - Treatment utilisation
AA 13 - Transmission and distribution storage capacity
AA 14 - Mains rehabilitation
AA 15 - Service connection rehabilitation (*)
Utility's operational sustainability
AA 16 - Main failures
Utility's human resource sustainability
AA 17 – Employees
ENVIRONMENTAL SUSTAINABILITY (I_3)
AA 18 - Utilization efficiency of water resources
AA 19 - Utilization efficiency of energy resources
AA 20 - Final destination of sludge from the water treatment

(*) – Not applicable to the kind of water supply systems analysed in this study.

The twenty performance indicators of this assessment system were aggregated into three main groups: *protection of the user's interests*, considering the service accessibility and the service quality; *sustainability of the utility*, to assess in what degree its technical and economic sustainability as well as its legitimate interests are protected; and *environmental sustainability*, to evaluate how the environmental aspects associated with the utility's activities are being considered.

The work presented herein only analyses the results obtained for a universe in which all utilities were compared considering all indicators, regardless of achieving a rating or not.

This universe of comparison implies that a correction is made to the weights assigned when a given indicator (*n.a.*) is not applicable to an utility or when the utility has not provided data regarding a particular indicator (*w.r.*).

Table 2 presents an example (for 2007) of the type of data that are published yearly in reports from IRAR concerning the rating for each performance indicator in order to highlight the great diversity of the corresponding scales.

Table 2: Performance indicators ratings published in IRAR's yearly report of 2007

	Performance Indicadors (2007)																		
W.S. Operator	AA01	AA02	AA03	AA04	AA05	AA06	AA07	AA08	AA09	AA10	AA11	AA12	AA13	AA14	AA16	AA17	AA18	AA19	AA20
A	96	0.41	0	100	99.99	100	1.73	0.24	0.45	3.5	0	60	0.4	0.6	1	2.4	2.2	0.4	100
B	33	0.39	0.08	100	98.11	100	1.02	0.52	0.12	17.6	85	29	1.3	0	61	20.8	14.4	0.5	100
C	100	0.45	0	99.58	99.96	96	2.25	0.21	0.25	3.3	100	60	1.8	0	2	2.4	0.8	0.3	100
D	58	0.51	0	99.85	99.42	100	1.53	0.46	0.26	12.4	0	62	1.7	0	8	8.1	9.3	0.5	100
E	74	0.53	0	99.71	99.63	75	1.26	0.4	0.14	19	1	60	1.2	0	0	6.5	4.9	0.5	100
F	100	0.31	0	100	99.96	100	1.94	0.16	0.19	1.4	0	48	0.7	0	4	1.5	1.2	0.4	100
G	25	0.53	0	100	99.15	76	3.16	0.45	0.1	8.3	0	46	2.3	0	6	11.5	w.r.	0.4	100
H	39	0.41	0	100	99.44	78	3	0.14	0.42	w.r.	98	n.a.	1	0	0	2.5	w.r.	0.5	n.a.
I	41	0.47	0	97.43	98.67	100	0.92	0.81	0.03	16.9	0	46	0.5	0.1	21	7.8	6.5	0.6	100
J	74	0.53	0.04	100	99.86	78	1.73	0.36	0.2	4.1	0	76	0.3	1.6	12	n.a.	1.5	0.5	100
K	100	0.54	0	100	100	na	1.61	0.34	0.16	2	0	n.a.	3.1	0.1	19	8.3	2	0.3	n.a.
L	46	0.53	0.05	100	99.49	84	1.75	0.38	0.1	4	0	37	2.2	2.2	13	10.2	3.8	0.4	100
M	n.a.	0.28	0	100	100	na	1.34	0.22	14.15	0.3	100	n.a.	1.2	0	6	1.3	0.3	0.4	n.a.
N	52	0.49	0	98.53	98.94	100	1.47	0.41	-0.01	16.7	0	77	1.8	0.1	16	5.2	16.2	0.4	85
O	n.a.	0.39	0.01	100	99.91	100	2.33	0.17	1.71	5.7	100	78	0.6	1.2	20	1.6	5.5	0.3	113

2.1 Criteria normalisation and aggregation

Considering that each IRAR's Performance Indicator may be assessed in a particular way, the resulting values of twenty different indicators usually cannot be directly combined. In order to overcome that problem, it was necessary to define a normalisation process to each of the indicators applied in GISEQ.

In the case of GISEQ, the suggested normalisation process is essentially based on fuzzy sets [10], i.e., Sigmoidal (S-shaped), J-shaped, Linear and Complex, defined for each indicator based either on IRAR or legislation standards. The *fuzzification* (or normalisation) expresses a membership grade that ranges from 0.0 to 1.0, indicating a continuous variation from non-membership (null or very bad indicator result) to complete membership (indicator result better than the overall reference values).

After all indicators were individually normalised to values between zero and one, they could be aggregated according to a decision rule.

The aggregation method proposed to GISEQ was based on a weighted linear combination, in which all criteria were combined through a weighted average.

That method allows for a total trade-off among criteria. It means that a very poor attribute, translated as a low score obtained for one criterion, can be compensated by a number of good attributes, translated as higher scores obtained for some other criteria.

Given the adopted structure of the IRAR's Performance Indicators System (Table 1) the criteria aggregation process resulted, primarily, in three sectoral indexes given by equation 1, and, after, the GISEQ value (Ig) has resulted of a similar weighted combination of those indexes (equation 2).

$$I_i = \Sigma\,(s_{i,j} \times w_{AA,j}) \qquad (1)$$

$$Ig = \Sigma\,(I_i \times w_{I,i}) \qquad (2)$$

2.2 Indicators weighting methods

Defining the relative importance of each indicator is a step in the multicriteria analysis methodology that requires a reliable and meticulous basis, namely through evaluations by analytical experts (academic, managers and advanced utility technicians).

Accordingly, an on-line survey was implemented, in which participants were asked to rate, on a scale of 1 (insignificant) to 7 (extremely significant) the importance of several indicators in each group and of each of the three groups for performance and sustainability. The results of this survey were used as a basis for setting up the three performance indicator weighting methods presented in Table 3.

Table 3: Methods applied in the indicators weighting

Weighting Method	
A	n-points scale
B	Pairwise comparisons
C	n-points scale modified (complemented with a ranking)

This was carried out in order to allow a sensitivity analysis of the GISEQ values and, consequently, of the changes in relative order of the several water suppliers in the established overall ranking.

The n-points scale method (method A) consists in the assignment of weights as a function of the averages of the results obtained through the survey for each performance indicator. This method produces weights that are similar in magnitude when the number of criteria is reduced (less than 4). For this reason and in view of the possibilities enabled by information gathered in the survey, it was possible to transform – in an innovative manner – the ratings assigned by each survey participant through a classic process of pairwise comparison of criteria (method B). This method assigns a weight to an indicator as a consequence of its comparison with another indicator. In the applying this methodology, the information provided by each participant allowed the construction of an $n \times n$ symmetrical matrix for each group. In order to complete the matrix, the 7-point scale used in the survey was converted to the 9-point scale adopted by Saaty [11] in the context of a decision making process known as Analytical Hierarchy Process (AHP).

Besides the two weight-assignment methods described, a new method (method C) was developed and based upon the values of the weights obtained using method A, through the assignment of a rating by ranking those weights. Therefore, the greatest rating corresponded to the highest weight ranking order and so forth, with rating decreasing with the ranking order. Naturally, the maximum rating depended on the total number of indicators in each one of the three groups under scrutiny.

Table 4 highlights the differences introduced by the three weight assignment methods by synthesising the values of the weights obtained for each performance indicator and sectoral index, using each method [12].

Table 4: Synthesis of the performance indicators' weights calculation, applying three different methods (%)

Indicator	Method A	Method B	Method C
AA01	16.37	0.16	0.14
AA02	17.08	18.13	22.73
AA03	17.08	16.48	22.73
AA04	16.13	13.29	9.09
AA05	19.00	25.89	27.27
AA06	14.34	9.99	4.55
Index 1	34.71	40.17	50.00
AA07	10.88	13.42	15.79
AA08	10.88	13.82	15.79
AA09	10.02	9.77	12.28
AA10	11.11	14.66	17.54
AA11	9.71	9.59	8.77
AA12	9.71	8.81	8.77
AA13	9.40	7.49	3.51
AA14	8.78	5.97	1.75
AA16	9.95	8.57	10.53
AA17	9.56	7.90	5.26
Index 2	33.10	32.68	33.33
AA18	33.41	35.00	33.33
AA19	34.14	35.91	50.00
AA20	32.45	29.10	16.67
Index 3	32.18	27.16	16.67

Because it displays the least differences between weights, method A is the most conservative, leading to a lesser risk of influencing the final utility ranking results.

Conversely, method C is the least conservative and carries the ability to introduce more significant changes to the final results.

3 Results and discussion

The scenarios under analysis in this paper refer to the performance of water managing entities for two consecutive years (2006 and 2007), for the same analytical universe and for the purpose of evaluating the influence of the weighting method in the final rating and ranking order of each entity.

The results obtained for the sectoral indices and for the GISEQ are presented in Tables 5 and 6. These regard fifteen managing entities and their ranking order in 2006 and 2007, respectively.

The developed model further allows the analysis, for each weight assignment method, of the evolution of ranking orders from 2006 to 2007, thus identifying the utilities that have gone up, gone down or have maintained their ranking position. Table 7 displays the observed evolution.

Table 5: Synthesis of the indices' calculation and the ranking position of water suppliers in from 2006

Utility	Method A					Method B					Method C				
	I1	I2	I3	Ig	RP	I1	I2	I3	Ig	RP	I1	I2	I3	Ig	RP
A	3.30	1.89	3.22	8.41	3	3.82	1.99	2.72	8.53	3	4.73	2.27	1.67	8.67	2
B	1.22	0.44	1.78	3.45	15	0.17	0.33	1.46	1.97	15	1.94	0.16	0.89	2.98	15
C	2.70	2.61	3.22	8.54	2	3.13	2.73	2.72	8.57	2	3.97	3.00	1.67	8.64	3
D	2.56	1.85	1.98	6.39	6	2.92	1.86	1.62	6.40	6	3.70	2.05	0.99	6.74	7
E	1.87	1.67	1.53	5.07	11	2.36	1.64	1.36	5.35	11	3.16	1.59	1.02	5.76	12
F	3.41	2.04	3.22	8.67	1	3.96	2.20	2.72	8.87	1	4.95	2.54	1.67	9.15	1
G	1.49	1.82	1.47	4.78	12	1.67	1.90	1.37	4.94	13	2.32	1.93	1.16	5.41	13
H	2.22	1.89	0.33	4.44	13	2.75	1.88	0.31	4.95	12	3.79	1.96	0.31	6.07	9
I	2.72	0.39	3.16	6.27	8	3.12	0.31	2.67	6.10	8	4.02	0.22	1.64	5.87	11
J	1.99	2.03	3.06	7.08	5	2.47	2.13	2.57	7.17	5	3.35	2.45	1.54	7.34	5
K	2.46	1.42	1.47	5.35	9	3.17	1.44	1.37	5.97	9	4.48	1.42	1.16	7.06	6
L	1.74	1.39	3.22	6.35	7	2.16	1.40	2.72	6.27	7	2.90	1.34	1.67	5.91	10
M	1.63	2.01	1.47	5.10	10	2.15	2.12	1.37	5.63	10	3.31	2.20	1.16	6.67	8
N	1.79	1.62	0.94	4.35	14	2.12	1.58	0.83	4.53	14	2.93	1.48	0.71	5.12	14
O	1.86	2.49	3.16	7.51	4	2.30	2.60	2.67	7.58	4	3.28	2.79	1.64	7.71	4

RP = ranking position

Table 6: Synthesis of the indices' calculation and the ranking position of water suppliers in from 2007

Utility	Method A					Method B					Method C				
	I1	I2	I3	Ig	RP	I1	I2	I3	Ig	RP	I1	I2	I3	Ig	RP
A	3.38	1.93	3.22	8.53	1	3.92	2.12	2.72	8.76	1	4.89	2.53	1.67	9.09	1
B	2.24	0.91	1.98	5.14	12	2.45	0.80	1.62	4.88	13	3.05	0.61	0.99	4.65	14
C	2.78	2.22	3.22	8.22	3	3.40	2.40	2.72	8.51	3	4.71	2.60	1.67	8.98	2
D	2.59	1.70	1.98	6.28	8	3.00	1.64	1.62	6.26	8	3.79	1.60	0.99	6.38	10
E	2.05	1.72	2.82	6.58	6	2.54	1.60	2.36	6.50	7	3.48	1.56	1.42	6.46	9
F	3.42	1.72	3.22	8.36	2	3.96	1.93	2.72	8.61	2	4.95	2.21	1.67	8.83	3
G	2.06	1.71	1.93	5.70	9	2.56	1.67	1.59	5.81	10	3.49	1.66	1.00	6.15	12
H	2.31	1.82	0.57	4.70	14	2.87	1.48	0.38	4.72	14	3.98	1.82	0.53	6.34	11
I	2.04	0.40	2.00	4.44	15	2.40	0.33	1.63	4.37	15	3.25	0.22	0.90	4.37	15
J	2.01	1.50	3.06	6.57	7	2.49	1.73	2.57	6.80	6	3.39	2.11	1.54	7.04	6
K	2.24	1.65	1.47	5.36	10	2.87	1.75	1.37	5.99	9	3.95	1.80	1.16	6.91	7
L	1.98	1.70	3.22	6.90	5	2.46	1.84	2.72	7.02	5	3.33	2.05	1.67	7.05	5
M	1.63	2.08	1.47	5.18	11	2.15	2.21	1.37	5.72	11	3.31	2.31	1.16	6.78	8
N	2.11	1.85	1.10	5.06	13	2.54	1.75	0.98	5.26	12	3.41	1.69	0.83	5.94	13
O	2.37	2.62	2.82	7.80	4	2.76	2.68	2.36	7.79	4	3.67	2.78	1.46	7.91	4

RP = ranking position

Table 7: Synthesis of the evolution of ranking orders from 2006 to 2007, for each weighting method

Water supplier	Index 1			Index 2			Index 3			GISEQ		
	Weighting methods											
	A	B	C	A	B	C	A	B	C	A	B	C
A	⇔	⇔	⇔	⇧	⇧	⇧	⇔	⇔	⇔	⇧	⇧	⇧
B	⇧	⇧	⇔	⇔	⇔	⇧	⇔	⇔	⇧	⇧	⇧	⇧
C	⇧	⇧	⇧	⇩	⇩	⇩	⇔	⇔	⇔	⇩	⇩	⇧
D	⇧	⇧	⇧	⇩	⇩	⇩	⇩	⇩	⇧	⇩	⇩	⇩
E	⇩	⇔	⇧	⇧	⇩	⇩	⇧	⇧	⇧	⇧	⇧	⇧
F	⇔	⇔	⇔	⇩	⇩	⇩	⇔	⇔	⇔	⇩	⇩	⇩
G	⇧	⇧	⇧	⇔	⇩	⇩	⇔	⇩	⇩	⇧	⇧	⇧
H	⇧	⇧	⇧	⇧	⇩	⇔	⇔	⇔	⇔	⇩	⇩	⇩
I	⇩	⇩	⇩	⇔	⇔	⇩	⇩	⇩	⇩	⇩	⇩	⇩
J	⇩	⇩	⇧	⇩	⇩	⇩	⇧	⇧	⇧	⇧	⇩	⇩
K	⇩	⇩	⇩	⇔	⇧	⇧	⇩	⇩	⇔	⇩	⇔	⇩
L	⇩	⇩	⇧	⇧	⇧	⇧	⇔	⇔	⇔	⇧	⇧	⇧
M	⇩	⇩	⇩	⇧	⇧	⇧	⇩	⇩	⇔	⇩	⇩	⇔
N	⇧	⇧	⇧	⇧	⇧	⇧	⇔	⇔	⇔	⇧	⇧	⇧
O	⇧	⇧	⇧	⇧	⇧	⇧	⇩	⇩	⇩	⇔	⇔	⇔

The results presented in this table confirm that, according to method A, seven entities improved their ranking versus seven others that obtained lower orders and one that managed to keep the GISEQ value. In terms of the sectoral indices, entities C, D, F, I and J are the only ones that have not evolved favourably from 2006 to 2007, since H, K and M, despite having their ranking order lowered, obtained an improved GISEQ value. From the results obtained using method B, six utilities improved their ranking, seven decreased it and two showed no changed. In general, the evolution trend in utility performance is very similar between methods A and B. As for method C, seven suppliers improved, while six have lowered their ranking and two maintained their position.

Generally, it is verified that the influence imparted by the weighting method in each utility's ranking is not only due to the change in values for each index but also to the relative order of the other utilities.

Table 8 shows, for each year, a synthesis of the variation of ranking position of each water supplier in terms of the weight assignment method applied.

Table 8: Synthesis of the evolution of ranking orders from 2006 to 2007, for each weighting method

Utility	2006			2007		
	A→B	A→C	B→C	A→B	A→C	B→C
A	I	D	D	E	E	E
B	D	E	E	I	I	I
C	I	I	I	E	D	D
D	I	I	I	E	I	I
E	I	I	I	I	I	I
F	I	E	E	E	I	I
G	I	I	E	I	I	I
H	I	D	D	E	D	D
I	D	I	I	E	E	E
J	I	E	E	D	D	E
K	I	D	D	D	D	D
L	D	I	I	E	E	E
M	I	D	D	E	D	D
N	I	E	E	D	E	I
O	I	E	E	E	E	E

I = increases; E= equal; D = decreases

4 Conclusions

With regards to the great importance imparted by the weights assigned to the performance indicators (criteria) in the final values of service quality indices, a sensitivity analysis was carried out for the weighting method to use.

In that sense, the global index values – obtained through methods A, B and C – for each water supplier were compared. Of these, two of them (B and C) show an innovative approach that could open new avenues for the development of theory in multicriteria analysis.

Of the six scenarios analysed in this paper, it is possible to conclude that: 2007 is, in general, the year for which the water utilities had a better performance, confirming the trend observed from the onset of the implementation of the performance evaluation system established by the regulatory entity; weighting method C is the one that produces the greatest dispersion in GISEQ values; the results obtained in method B are slightly superior in relation to the ones obtained from method A.

The developed model for the definition of the different indices allows the establishing of a global and sectoral ranking, evaluate the evolution of the performance of each water supplier in their different domains, and identify the corresponding weaknesses and potential, contributing to a continuous improvement of service quality in water supply systems. The evaluation process thus developed facilitates benchmarking, providing a relevant contribution to the sustainability of an activity sector that, despite enjoying weak competition, provides a vital service to the community, namely in the protection of public health and in being an important factor for social and economic development.

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