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Assessment of Environmental Sustainability in Health Care Organizations

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Abstract: Health organizations should be a reference in Corporate Social Responsibility and the encouragement of environmental sustainability, since the protection of the environment implicitly involves the development of preventive measures in the field of health. Concern for the environment has typically been focused on manufacturing plants; however, health care organizations (HCO) are the only ones which generate all the classes of waste, with 20% of them dangerous due to their infectious, toxic or radioactive nature. Despite the extensive literature analysing environmental matters, there is no model to evaluate environmental sustainability in HCO's objectively. This contribution presents a Multi-Criteria Decision Analysis model which integrates the Fuzzy Analytic Hierarchy Process and utility theory to evaluate environmental sustainability in HCO's. The model uses criteria assessed by number of admissions and services provided annually; in this way the results can be compared over time within an organization and between different organizations, providing a tool for comparison or benchmarking between HCO's. The model has been applied to two HCO's of very different sizes.

Keywords: enviromental sustainability; health care organizations; multicriteria techniques.

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1. Introduction

Healthcare organizations should encourage economic, social and environmental sustainability, in order to be references in corporate social responsibility. To do this, they must strike a balance between economic and health needs, so as to guarantee sustainable development. Among other things, this implies minimizing the environmental impact, since protection of the environment requires developing preventive measures in healthcare [1].

The literature contains a large number of contributions on environmental issues in different types of manufacturing organizations [2-6]. Nevertheless, in the area of health organizations the contributions are practically nonexistent. However, health care organizations are the only companies which produce all the classes of waste; also, 20% of the waste produced is considered dangerous, being infectious, toxic or radioactive [7].

Incorrect handling of hospital waste is a risk for people, in the form of spreading of infectious diseases, and also for the environment. Due to the serious implications for the environment, Health Care Organizations (HCO's) have over the last decade in Spain been introducing, albeit belatedly, environmental management into their strategic objectives.

This research sets out a model using a multicriteria approach which serves as an internal audit of the EMS used by an HCO. It can be used to evaluate objectively and continuously the performance of actions for environmental improvement. Unlike a traditional audit, the model described takes advantage of the use of multicriteria techniques, as not all environmental matters are of equal importance. This gives the HCO a model that is easy to apply, with criteria specific to healthcare and which allows environmental sustainability to be controlled over time.

2. Multicriteria decision analysis model

The mathematical foundations of AHP can be viewed in [8-10].

The procedure for applying fuzzy AHP can be seen in [11-13].

A triangular fuzzy number is defined $\tilde{a} = (l, m, u)$, where l and u are the lower and upper limits respectively and m is the modal value. $\tilde{a}$ is defined by the membership function $\mu_{\tilde{a}}(x): \Re \rightarrow [0,1]$ according to equation (1) [11].

$$\mu_{\tilde{a}}(x) = \begin{cases} \dfrac{x}{m-l} - \dfrac{l}{m-l}, & x \in [l, m] \\ \dfrac{x}{m-u} - \dfrac{u}{m-u}, & x \in [m, u] \\ 0, & otherwise \end{cases} \tag{1}$$

with $l \leq m \leq u$; l and u are the lower and upper bounds of the fuzzy number and m the modal value.

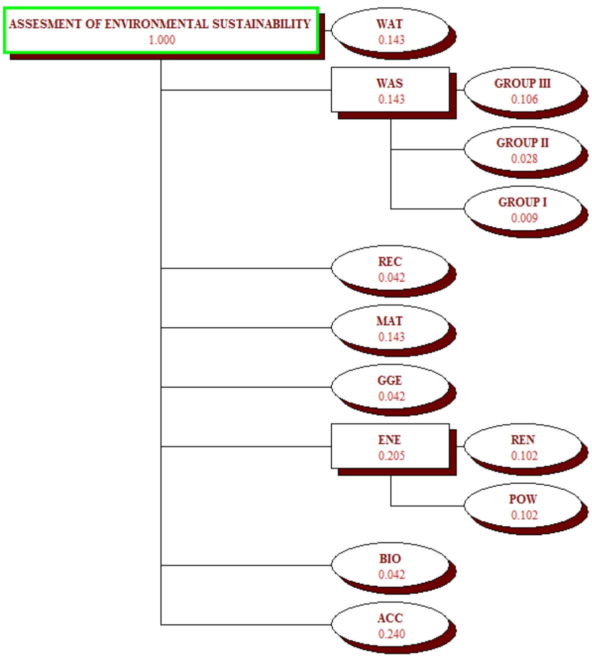
$\tilde{A}$ represents a fuzzified reciprocal n-by-n judgment matrix with $\tilde{a}_{ij}$ the fuzzy comparison value between criteria i and j at the same level of hierarchy, $\tilde{a}_{ij} \forall$ i, j $\in$ {1, 2, …, n}.

$$\tilde{A} = \begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & (1,1,1) \end{bmatrix} \tag{2}$$

The decision criteria have been chosen after analysing many environmental declaration documents published by different health care organizations. The hierarchy structure of the model can be seen in Figure 1. The criteria and subcriteria used in the multicriteria model are:

- Water consumption (WAT). For healthcare organizations water consumption lower than the previous year is recommended.
- Energy efficiency (ENE). Two factors are assessed:
  a) The annual consumption of electricity, refrigerating energy, thermal energy and natural gas (POW).
  b) The annual consumption of renewable energy (REN).
- Waste production (WAS). Annual waste generation is assessed (10^3 kg). It is divided into the following subcriteria:
  a) Group I waste (GROUP I). This consists of solid urban waste.
  b) Group II waste (GROUP II). This refers to sanitary waste
  c) Group III waste (GROUP III). This is dangerous waste, including industrial oils, batteries, non-halogen solvents, liquids for radiology, out-of-date medicines, anatomical remains in formaldehyde, etc.
- Greenhouse gas emissions (GGE). Annual greenhouse gas emissions are assessed (10^3 kg), such as CO_2, CH_2 and N_2O.
- Material consumption (MAT). Annual consumption (10^{-3} kg) of different materials such as fluorescents, glutaraldehyde, computer parts, ethylene oxide, paper, batteries, Petri dishes, etc.
- Recycling (REC). Annual quantity (10^{-3} kg) of waste recycled.
- Environmental accidents (ACC). The existence of serious environmental accidents such as spillage of dangerous substances on the ground, outbreaks of legionnaire's disease, x-ray emissions, etc., is measured.
- Biodiversity (BIO). The impact of the HCO on the environment, that is, its adaptation to the rural and wooded environment is assessed.

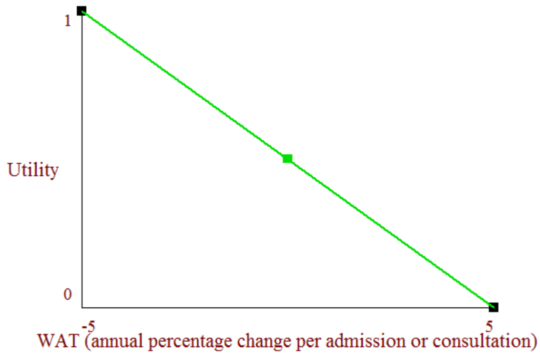
Figure 1. Hierarchy.



Each criterion has an associated descriptor which allows each HCO to be assessed objectively. The quantitative descriptors are assessed according to the number of admissions or services provided annually by the HCO, since consumption of materials, energy, etc. depend on the activity or service provided. In this way the results are comparable over time for an HCO and they are also comparable between different health care organizations, giving a tool for comparison or benchmarking. Also, the percentage change is measure each year with respect to the previous year.

To produce the utility functions of the criteria related to consumption, it was established that the optimum situation is to show a drop of 5% with respect to the consumption of the previous year per admission or visit. The worst situation is where consumption is 5% higher than the previous year per admission or visit. In the case of the criterion recycling, an increase of 5% with respect to the previous year's consumption per admission or visit is considered the optimum value, whereas a drop of 5% is considered the worst result. The utility function designed for water consumption is shown in Figure 2.

Figure 2. Utility function used for criterion water consumption (WAT).



An expert in environmental matters was used to obtain a pairwise comparison matrix for the decision criteria applying a fuzzy scale. This expert performs the pairwise comparisons of $\tilde{A}$ applying the fuzzy scale set out in Table 1.

Table 1. Fuzzy scale.

Linguistic scale	Triangular fuzzy numbers	Triangular fuzzy reciprocal numbers
Equally important	$(1,1,1)$	$(1,1,1)$
Judgment values between equally and moderately	$(1,2,3)$	$(1/3,1/2,1)$
Moderately more important	$(2,3,4)$	$(1/4,1/3,1/2)$
Judgment values between moderately and strongly	$(3,4,5)$	$(1/5,1/4,1/3)$
Strongly more important	$(4,5,6)$	$(1/6,1/5,1/4)$
Judgment values between strongly and very strongly	$(5,6,7)$	$(1/7,1/6,1/5)$
Very strongly more important	$(6,7,8)$	$(1/8,1/7,1/6)$
Judgment values between very strongly and extremely	$(7,8,9)$	$(1/9,1/8,1/7)$
Extremely more important	$(8,9,9)$	$(1/9,1/9,1/8)$

The value of fuzzy synthetic extent $\tilde{S}_i$ with respect to the i-object is defined as:

$$\tilde{S}_i = \sum_{j=1}^{m} \tilde{a}_{ij} \otimes [\sum_{i=1}^{n} \sum_{j=1}^{m} \tilde{a}_{ij}]^{-1} \tag{3}$$

where $\tilde{a}_{ij}$ is a triangular fuzzy number of the decision matrix $\tilde{A}$ with n objects and m goals.

The values of fuzzy synthetic extents obtained from the judgments matrix are:

$\tilde{S}_{ACC} = (0.102, 0.270, 0.436); \tilde{S}_{ENE} = (0.074, 0.222, 0.379); \tilde{S}_{WAS} = (0.062, 0.159, 0.265)$
$\tilde{S}_{WAT} = (0.062, 0.159, 0.265); \tilde{S}_{MAT} = (0.062, 0.159, 0.265); \tilde{S}_{GGE} = (0.043, 0.085, 0.142)$
$\tilde{S}_{REC} = (0.043, 0.085, 0.142); \tilde{S}_{BIO} = (0.043, 0.085, 0.142)$

The values of $\tilde{S}_i$ are compared and the degree of possibility of $\tilde{S}_j = (l_j, m_j, u_j) \geq \tilde{S}_i = (l_i, m_i, u_i)$ is calculated from equation (4).

$$V(\tilde{S}_j \geq \tilde{S}_i) = height(\tilde{S}_i \cap \tilde{S}_j) = \begin{cases} 1, & if\ m_j \geq m_i \\ 0, & if\ l_i \geq u_j \\ \dfrac{l_i - u_j}{(m_j - u_j) - (m_i - l_i)}, & otherwise \end{cases} \tag{4}$$

Appling equation (4) to the model:

$V(\tilde{S}_{ACC} \geq \tilde{S}_{ENE}) = 1.000$ $V(\tilde{S}_{ACC} \geq \tilde{S}_{WAS}) = 1.000$, $V(\tilde{S}_{ACC} \geq \tilde{S}_{WAT}) = 1.000$, $V(\tilde{S}_{ACC} \geq \tilde{S}_{MAT}) = 1.000$, $V(\tilde{S}_{ACC} \geq \tilde{S}_{GGE}) = 1.000$, $V(\tilde{S}_{ACC} \geq \tilde{S}_{REC}) = 1.000$, $V(\tilde{S}_{ACC} \geq \tilde{S}_{BIO}) = 1.000$.

$V(\tilde{S}_{ENE} \geq \tilde{S}_{ACC}) = 0.853$; $V(\tilde{S}_{ENE} \geq \tilde{S}_{WAS}) = 1.000$, $V(\tilde{S}_{ENE} \geq \tilde{S}_{WAT}) = 1.000$ $V(\tilde{S}_{ENE} \geq \tilde{S}_{MAT}) = 1.000$, $V(\tilde{S}_{ENE} \geq \tilde{S}_{GGE}) = 1.000$, $V(\tilde{S}_{ENE} \geq \tilde{S}_{REC}) = 1.000$, $V(\tilde{S}_{ENE} \geq \tilde{S}_{BIO}) = 1.000$.

$V(\tilde{S}_{WAS} \geq \tilde{S}_{ACC}) = 0.595$, $V(\tilde{S}_{WAS} \geq \tilde{S}_{ENE}) = 0.750$, $V(\tilde{S}_{WAS} \geq \tilde{S}_{WAT}) = 1.000$ $V(\tilde{S}_{WAS} \geq \tilde{S}_{MAT}) = 1.000$, $V(\tilde{S}_{WAS} \geq \tilde{S}_{GGE}) = 1.000$, $V(\tilde{S}_{WAS} \geq \tilde{S}_{REC}) = 1.000$, $V(\tilde{S}_{WAS} \geq \tilde{S}_{BIO}) = 1.000$.

$V(\tilde{S}_{WAT} \geq \tilde{S}_{ACC}) = 0.595$, $V(\tilde{S}_{WAT} \geq \tilde{S}_{ENE}) = 0.750$, $V(\tilde{S}_{WAT} \geq \tilde{S}_{WAS}) = 1.000$ $V(\tilde{S}_{WAT} \geq \tilde{S}_{MAT}) = 1.000$, $V(\tilde{S}_{WAT} \geq \tilde{S}_{GGE}) = 1.000$, $V(\tilde{S}_{WAT} \geq \tilde{S}_{REC}) = 1.000$, $V(\tilde{S}_{WAT} \geq \tilde{S}_{BIO}) = 1.000$.

$V(\tilde{S}_{MAT} \geq \tilde{S}_{ACC}) = 0.595$, $V(\tilde{S}_{MAT} \geq \tilde{S}_{ENE}) = 0.750$, $V(\tilde{S}_{MAT} \geq \tilde{S}_{WAS}) = 1.000$ $V(\tilde{S}_{MAT} \geq \tilde{S}_{WAT}) = 1.000$, $V(\tilde{S}_{MAT} \geq \tilde{S}_{GGE}) = 1.000$, $V(\tilde{S}_{MAT} \geq \tilde{S}_{REC}) = 1.000$, $V(\tilde{S}_{MAT} \geq \tilde{S}_{BIO}) = 1.000$.

$V(\tilde{S}_{GGE} \geq \tilde{S}_{ACC}) = 0.177$, $V(\tilde{S}_{GGE} \geq \tilde{S}_{ENE}) = 0.330$, $V(\tilde{S}_{GGE} \geq \tilde{S}_{WAS}) = 0.520$ $V(\tilde{S}_{GGE} \geq \tilde{S}_{WAT}) = 0.520$, $V(\tilde{S}_{GGE} \geq \tilde{S}_{MAT}) = 0.520$, $V(\tilde{S}_{GGE} \geq \tilde{S}_{REC}) = 1.000$, $V(\tilde{S}_{GGE} \geq \tilde{S}_{BIO}) = 1.000$.

$V(\tilde{S}_{REC} \geq \tilde{S}_{ACC}) = 0.177$, $V(\tilde{S}_{REC} \geq \tilde{S}_{ENE}) = 0.330$, $V(\tilde{S}_{REC} \geq \tilde{S}_{WAS}) = 0.520$ $V(\tilde{S}_{REC} \geq \tilde{S}_{WAT}) = 0.520$, $V(\tilde{S}_{REC} \geq \tilde{S}_{MAT}) = 0.520$, $V(\tilde{S}_{REC} \geq \tilde{S}_{GGE}) = 1.000$, $V(\tilde{S}_{REC} \geq \tilde{S}_{BIO}) = 1.000$.

$V(\tilde{S}_{BIO} \geq \tilde{S}_{ACC}) = 0.177$, $V(\tilde{S}_{BIO} \geq \tilde{S}_{ENE}) = 0.330$, $V(\tilde{S}_{BIO} \geq \tilde{S}_{WAS}) = 0.520$ $V(\tilde{S}_{BIO} \geq \tilde{S}_{WAT}) = 0.520$, $V(\tilde{S}_{BIO} \geq \tilde{S}_{MAT}) = 0.520$, $V(\tilde{S}_{BIO} \geq \tilde{S}_{GGE}) = 1.000$, $V(\tilde{S}_{BIO} \geq \tilde{S}_{REC}) = 1.000$.

Next, the minimum degree possibility of $V(\tilde{S}_j \geq \tilde{S}_i)$ is calculated for i, j =1, 2, …, k. and, the weight vector W' is defined:

$$W' = (\min V(\tilde{S} \geq \tilde{S}_1), \min V(\tilde{S} \geq \tilde{S}_2), ..., \min V(\tilde{S} \geq \tilde{S}_k))^T \tag{5}$$

Therefore, the minimum of the degrees of possibility are:

$$\min V(\tilde{S}_{ACC} \geq \tilde{S}_i) = 1.000,\ \min V(\tilde{S}_{ENE} \geq \tilde{S}_i) = 0.853,\ \min V(\tilde{S}_{WAS} \geq \tilde{S}_i) = 0.595,$$

$$\min V(\tilde{S}_{WAT} \geq \tilde{S}_i) = 0.595,\ \min V(\tilde{S}_{MAT} \geq \tilde{S}_i) = 0.595,\ \min V(\tilde{S}_{GGE} \geq \tilde{S}_i) = 0.177,$$

$$\min V(\tilde{S}_{REC} \geq \tilde{S}_i) = 0.177,\ \min V(\tilde{S}_{BIO} \geq \tilde{S}_i) = 0.177.$$

After normalizing, the resulting non-fuzzy weight vector W is $W = (0.240, 0.205, 0.143, 0.143, 0.143, 0.042, 0.042, 0.042)$.

A similar process is followed with the subcriteria of Waste and Energy efficiency.

To assess the consistency of the judgments given by the decision maker the Consistency Index (CI) is used to assess the consistency of the judgements given by the decision maker [8].

$$CI = (\lambda_{max} - n)/(n - 1) \tag{6}$$

The Consistency Ratio (CR) is defined as the quotient of the CI and the Random Consistency Index (RCI) for a matrix of similar size. If CR is less than 0.05 for a 3x3 matrix, 0.08 for a 4x4 matrix and 0.1 for matrices of higher order, then the judgement matrix is consistent [8]. To calculate the CI in fuzzy AHP the central value of λ_{max} will be used because in the symmetry of a fuzzy number, the central value corresponds to the centroid of the triangular area [14].

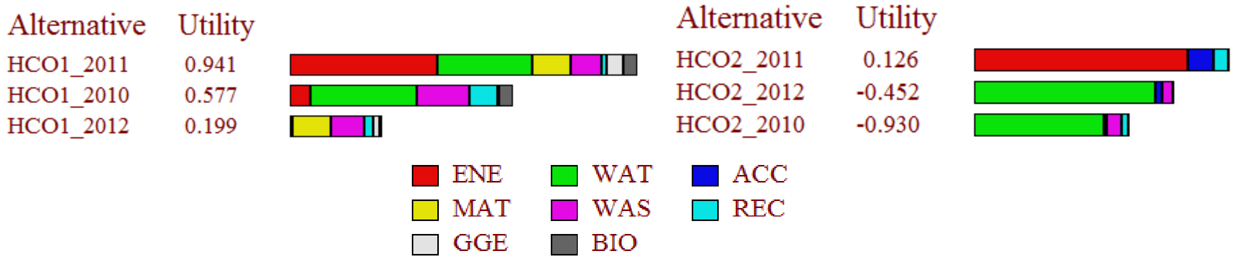
The CR obtained is 0 in the pairwise comparison matrix of the criteria and 0 and 0.069 in the pairwise comparison matrix of the subcriteria with respect to energy efficiency and materials respectively, and so the judgements made are consistent.

3. Results

The first Health Care Organization (HCO1) analysed is a general hospital with a mean annual level of service of 22,000 admissions and 180,000 consultations. The second Health Care Organization (HCO2) analysed is a walk-in centre with some 65,000 consultations annually.

It has been considered a cutoff value for the quantitative criteria of ±100%. The results provided by the model for 2010, 2011 and 2012 are shown in Figure 3. Because the cut-off value is fixed at ±100%, the HCO2 has negative utility values in 2010 and 2012; in this way, an alternative is penalized when it gives high negative change percentages.

Figure 3. Assessment of Health Care Organizations.



This assessment model requires that there be continuous annual improvement and also that these improvements are carried out on the various criteria used. In this way, the aims of both the organization assessed, who consider it a positive thing to show a negative annual trend in the criteria related to consumption, can be satisfied, while the final aim sought is to have an annual percentage change per number of admissions/visits of -100%. For recycling or renewable energy consumption criteria the objective is fixed at +100%.

In the case of HCO1 a significant improvement is seen in 2011 due to a large drop in energy and water consumption with values of -13.78% and -13.01% respectively per admission with respect to 2010. However, in 2011 there was a large increase in dangerous waste. In 2012 there was an increase in the consumption of resources such as water (6.26%), energy (7.48%) and materials (1.32%) with respect to 2011 per hospital admission which caused a decrease in utility.

In HCO2 there were also better results in 2011 with a decrease in energy consumption of 16.12% per hospital visit with respect to 2010. This centre has no source of renewable energy and so this criterion does not give a positive contribution to the assessment. Consumption of materials showed a significant drop of -55.74% per visit with compared to 2010. 2012 shows negative results, due mainly to an increase in consumption of energy (2.71%) and raw materials (143.22%).

It should be borne in mind that the refurbishing and updating of some medical facilities or services leads in many cases to the elimination of accumulated waste products, with an accompanying negative effect on the results given by the model. A similar effect is attributable to the opening of new health care services or facilities.

4. Conclusions

Unlike in a traditional audit, the model takes advantage of the use of Multi-Criteria Decision Analysis techniques; these allow objective modelling of the decision problem since one or more decision makers give judgements, which provide a value for the importance of each environmental question to the organization. It also has the capacity to analyse both quantitative and qualitative criteria simultaneously, and guarantees no redundancy in the assessment of items. Additionally, the fuzzy approach takes account of the uncertainty, vagueness or ambiguity of the judgements given by the decision makers.

This assessment model makes it obligatory to carry out continuous improvements and that this is done with the various criteria used. The model uses criteria assessed by number of admissions and services provided annually; in this way the results can be compared over time within an organization and between different organizations, providing a tool for comparison or benchmarking between HCO's.

Conflict of Interest

The author declares no conflict of interest.

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