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Regional hospital solid waste assessment using the evidential reasoning approach

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HIGHLIGHTS

► We assess the regional hospital solid waste using evidential reasoning (ER) approach.
► Different types of uncertainties are considered in our assessment.
► We used Dempster–Shafer theory to aggregate multiple hospital solid waste assessment criteria.
► Distributed assessment for each regional hospital is provided by the proposed methodology.
► Application of the proposed framework will help pointing out the most polluting hospital.

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ABSTRACT

Hospital solid waste assessment is regularly characterized by a large number of known criteria that are both qualitative and quantitative in nature. The qualitative criteria can only be assessed by human judgments, which predictably engage a variety of uncertainties such as fuzziness and ignorance. Therefore, hospital solid waste assessments need to be analyzed and modeled using approaches that can handle uncertainties. The evidential reasoning (ER) approach can be utilized for such an analysis. In this paper, perhaps for the first time, the ER approach is applied to regional hospital solid waste assessment. The assessment criteria are characterized by a set of assessment grades assumed to be commonly exclusive and communally exhaustive. All assessment information, incomplete or complete, qualitative or quantitative, and imprecise or precise, are modeled using a cohesive belief structure. The ER approach will be used to aggregate multiple hospital solid waste assessment criteria, resulting in distributed assessment for each alternative. The proposed methodology is applied for regional hospital solid waste assessment in the province of Khuzestan, Iran.

1. Introduction

Due to the fact of industrialization and population growth, hospital solid waste disposal, which includes an extensive scope of contagious hazardous pollutants, has turned out to be one of the most important environmental issues. A limited number of studies related to the hospital solid waste management have been made, in particular for the improvement of existing schemes for hospital waste assessment.

Liberti et al. (1996) proposed a model to present optimal operating policies for a general waste management system involving characterization, handling (collection, storage, transportation), and burning the hospital wastes created by a large sanitary area. Awad et al. (2004) did some statistical analyses to develop prediction models for the quantity of waste produced at two private and public hospitals located in Jordan. In their models, number of beds and patients, and types of hospitals were recognized as significant criteria. Multiple regressions were also used to estimate the generated waste quantity.

Morrissey and Browne (2004) had a review on various types of models that are used in the area of hospital, municipal, and industrial waste management and pointed out some principal weaknesses of these models. According to their work, most of the models in the literature are decision support models being divided into three classes based on: life cycle assessment, cost–benefit analysis, and multi-criteria decision making. Vego et al. (2008) modeled the efficacy of developing a waste management system in the coastal part of Croatia. Two multi-criteria decision-making (MCDM) methods, GAIA and PROMETHEE, were used for analysis and assessment of options. The problem was investigated according to numerous social, economic, and ecological criteria sets that were recognized as related to the decision-making procedure. The GAIA and PROMETHEE methods were shown to be efficient tools for investigating the considered problem. Such an attitude delivered new awareness to waste management

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planning (WMP) at the strategic level, and provided an aim for rethinking about the current documents of strategic waste management in Croatia.

Ulukan and Kop (2009) compared several collection methods using fuzzy TOPSIS method. To study the solid waste recovery, they took into consideration the social, financial, and also environmental criteria. The innovation of their study was that the decision making procedure was enhanced by using the environmental impact data. They assessed the environmental special effects via life cycle assessment approach.

Zamali et al. (2009) focused on the expansion of a new MCDM method with giving emphasis to the several natures of the input data in the assessment procedure to select the best way for disposing municipal solid wastes (MSW). Through using both fuzzy ideal solution technique and the analytic hierarchy process (AHP), the usage of dilation concept was fully hired in their methodology. The results revealed that their methodology is effective in dealing with the uncertainty of the primary data and simplifies an organized decision making.

De Feo and De Gisi (2010) verified the efficiency of applying a new criteria weighting tool for ranking a list of municipal solid waste management sites using AHP. In order to study both the social and technical criteria; the usage of the "priority scale" was proposed to simply gather non-conflicting criteria preferences by the decision-makers. The proposed technique was used to the site selection of a composting plant in a region suffering from a severe MSW emergency.

Du et al. (2011) set up a hybrid model of analytical hierarchy process and fuzzy comprehensive evaluation for a municipal solid waste management option selection. Dalian Development Area of China was chosen as their case study to validate the practicality of their model for municipal solid waste management option selection.

Kumar and Hassan (2012) used AHP for selecting an appropriate landfill site for disposal of SWM. Various criteria such as distance from residential places, existence of water-bodies and forests, transport connectivity, groundwater table level and geology were considered in the AHP-based decision making.

Arthur P. Dempster introduced the evidence theory in the 1960s. Later, this theory was refined and extended by Glen Shafer in the 1970s. Hence, this theory is known as the Dempster–Shafer theory (or the D–S theory) of evidence. The D–S theory is interrelated to the Bayesian probability theory. That is, they both deal with subjective beliefs. On the other hand, according to Shafer (1976), the Bayesian probability theory is included in the evidence theory as a special case. The largest difference being in that the latter is able to deal with ignorance, while the former is not and its subjective beliefs have to obey the probability rules.

To date, the D–S theory has found extensive applications in many areas such as expert systems, artificial intelligence (AI), pattern recognition, knowledge and database discovery, information fusion, risk assessment, multiple attribute decision analysis (MADA), etc. (Denoeux and Zouhal, 2001; Hullermeier, 2001; Beynon, 2005a; Davis and Hall, 2003; Xu et al., 2006; Soundappan et al., 2004; Cobb and Shenon, 2003).

In this paper, a new framework is proposed for hospital solid waste assessment. Different criteria can be employed for the evaluation of the pollution caused by the existing hospital solid wastes and the efficacy of the existing management schemes. For ranking the hospitals and determining the share of each in the whole hospital solid waste pollution load, a multiple criteria decision making technique, namely evidential reasoning (ER) approach, is used. The suggested methodology is assessed using data from 40 hospitals in the province of Khuzestan in which, most of the hospital solid wastes are disposed, stored, or burnt in open spaces. In some cases, these solid wastes are disposed in domestic waste landfills, which can cause considerable environmental and healthiness problems.

2. The Dempster–Shafer theory of evidence

Let $\theta = \{H_1,\ldots,H_N\}$ be a set of propositions or hypotheses. This set of hypotheses is called the frame of discernment. The basic probability assignment (bpa) of this set is a mass function $m: 2^\theta \rightarrow [0,1]$ satisfying the following constraints:

$$\sum_{A\subseteq\theta} m(A) = 1 \text{ and } m(\phi) = 0, \tag{1}$$

where A is any subset of θ, ϕ is an empty set, and $2^\theta = \{\phi,\{H_1\},\ldots\{H_N\},\{H_1, H_2\},\ldots,\{H_1,H_N\},\ldots,\theta\}$ is the power set of θ that contains all subsets of θ. $m(A)$ is the belief (also called probability mass) allocated to A and is how sturdily the evidence supports A. All the allocated probabilities sum to unity and there is no belief in the empty set (ϕ). The allocated probability to θ, i.e. $m(\theta)$, would be the degree of ignorance.

Each subset $A \subseteq \theta$ such that $m(A) > 0$ is a central element of m. All the related central elements are jointly named as the body of evidence.

Associated with each bpa is the plausibility measure, *Pl*, and the belief measure, *Bel*, which are calculated by using the following equations, respectively:

$$Pl(A) = \sum_{A\cap B\neq\phi} m(B), \tag{2}$$

$$Bel(A) = \sum_{B\subseteq A} m(B), \tag{3}$$

where A and B are subsets of θ. $Pl(A)$ is the potential support to A, i.e. the whole quantity of belief that may possibly be allocated to A; $Bel(A)$ is the precise support to A. i.e. the belief of the hypothesis A being factual. $[Bel(A), Pl(A)]$ represent the interval support to A i.e. the lower and upper bounds of the probability allocated to A being factual. These two functions can be related by the equation:

$$Pl(A) = 1 - Bel(\bar{A}), \tag{4}$$

where $\bar{A}$ is the complement of A. The distinction between *Pl* and *Bel* of a set A is called the assessment ignorance of the set A (Shafer, 1976).

The Dempster's rule of combination is the heart of the evidence theory by which the evidence from diverse foundations is aggregated or combined. The rule presumes that the data sources are not dependent and employs the orthogonal sum to aggregate various belief constructions:

$$m = m_1 \oplus m_2 \oplus \ldots \oplus m_K, \tag{5}$$

where $\oplus$ denotes the combination operator. For two belief structures m_1 and m_2, the Dempster's rule of combination would be written as follows: (Wang et al., 2006)

$$[m_1 \oplus m_2](C) = \begin{cases} 0, & C = \phi, \\ \dfrac{\sum_{A\cap B=C} m_1(A)m_2(B)}{1 - \sum_{A\cap B=\phi} m_1(A)m_2(B)}, & C \neq \phi, \end{cases} \tag{6}$$

where A and B are both central fundamentals and $[m_1 \oplus m_2](C)$ is a mass function (bpa). The denominator, $1 - \sum_{A\cap B=\phi} m_1(A)m_2(B)$ is the normalization factor, $\sum_{A\cap B=\phi} m_1(A)m_2(B)$ is named as the degree of conflict, which measures the conflict between the portions of evidence (George and Pal, 1996).

The Dempster's rule of combination is shown to be both associative $((m_1 \oplus m_2) \oplus m_3 = m_1 \oplus (m_2 \oplus m_3))$ and commutative $(m_1 \oplus m_2 = m_2 \oplus m_1)$ (Shafer, 1976). These two properties indicate that evidence can be aggregated in any order. Hence, in the case of various belief constructions, the aggregation of evidence can be done in a pairwise way.

Note that the basic appliance of the D–S theory and the aggregation rule can result in illogical termination in the aggregation of various portions of evidence in conflict (Murphy, 2000). This concern is