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A new multi criteria decision making approach for medical imaging systems considering risk factors

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ABSTRACT

Effective and good quality imaging is important for medical decision-making and can reduce unnecessary costs and procedures. Therefore, decision making regarding any technology can present serious problems for healthcare centers with multi criteria decision making problems (MCDM). This paper is the first to develop the fuzzy axiomatic design with risk factors (RFAD) approach and to use it in multi attribute comparisons of medical imaging systems in a university hospital. Although most MCDM approaches in the literature treat risk factors as separate criteria, in real life every alternative has its own risks related to each criterion. The proposed approach integrates the risk factors in each criterion and calculates the information content to compare alternatives. This paper applies three different approaches to MCDM problems related to the selection of medical imaging systems for a university hospital.

1. Introduction

Medical imaging refers to several different technologies that are used to view the human body in order to diagnose, monitor, or treat medical conditions. Each type of technology gives different information about the area of the body being studied or treated, related to possible disease, injury, or the effectiveness of medical treatment. The selection of medical imaging systems is especially important because it supports the correct and timely diagnosis and treatment of hospital patients. Since the discovery of X-rays by W.C. Roentgen in 1895, medical imaging has made significant contributions to medicine. Over the last 50 years, a variety of imaging modalities have been developed including radionuclide imaging, ultrasound (US), computed tomography (CT), magnetic resonance imaging (MRI), and digital radiography. They are among the most important clinical diagnostic tools in medicine today [32]. Medical imaging systems technology has advanced to be able to detect pathologies at a very early stage, thereby improving the patient's prognosis dramatically, but this technology is expensive so the evaluation and selection of medical systems and equipment requires detailed attention and careful analyses.

The selection of an optimal medical imaging system for a hospital among various alternatives based on different criteria is referred to as a multi criteria decision making (MCDM) problem. Several approaches and relevant methods have been presented to handle MCDM problems including scoring models, analytic hierarchy process (AHP), analytic network process (ANP), utility models, technique for order of preference by similarity to ideal solution (TOPSIS) and outranking methods [2]. The most common MCDM method is the AHP presented by Saaty [37]. There have been many applications of AHP for selection and evaluation of projects and technology in health care settings. Turri [45] described the application of AHP to select a MRI vendor for a hospital using price, technology, sitting, service, service contract, cryogen contract, and patient comfort as criteria. There are also medical applications of AHP that included medical product design optimization ([17,18]). Chatburn [9], Sloane [38], and Sloane et al. [39] considered the evaluation of ventilators for hospital purchase. Cho and Kim [10] applied AHP for the selection of medical devices and materials for grants by the Korean Ministry of Health and Welfare. Tak [44] discussed the application of AHP to evaluate image quality of both conventional and computed radiology as part of a benchmarking study in Hong Kong. Rossetti and Selandari [36] applied AHP to decide whether a fleet of mobile robots can replace a traditional human-based delivery system in clinical laboratories and hospital pharmacies. Liberatore and Nydick [33] reviewed and analyzed a large amount of relevant literature focusing on the applications of AHP to solve important problems in medical and health care decision-making. Subramanian and Ramanathan [40] reviewed AHP literature in operations management including the healthcare studies. Kahraman et al. [25] used fuzzy AHP (FAHP) to evaluate possible investments in health research.

Although there have been many applications of AHP in health care, no application of axiomatic design (AD) methodology for

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selection of medical imaging systems for a hospital was found in the literature. AD principles including the information axiom presents an opportunity for multi attribute evaluation ([41,43]). In this study, a new model based on the information axiom is generated that can support decision-makers in the medical imaging system selection process for the first time. In order to avoid the pitfalls of preceding methods, the AD method enables decision makers to evaluate both qualitative and quantitative criteria together. The traditional AD methodology has been applied by many researchers in various applications such as Kulak et al. [29], Gonçalves-Coelho and Mourão [14], Bahadir and Satoglu [2]. Kulak et al. [27] reviewed and classified the applications of AD principles in the literature.

Recently, the AD methodology has been applied to different cases in fuzzy environment as fuzzy axiomatic design (FAD). FAD provides an ordering of candidate designs and allows the comparison of design concepts under conditions of uncertainty. In considering this, fuzzy decision models are proposed as the most suitable method because this method can easily model linguistic uncertainty. If one of the criteria is not satisfied, FAD has the capability to eliminate a concept. In such a case, a concept has to be discarded even though it might achieve excellent results for all but one. This attribute does not exist in specific methods such as AHP. FAD also provides the opportunity to evaluate design concepts with a combination of qualitative and quantitative design criteria ([1]). The application trends of FAD have focused on design review ([16]), manufacturing system evaluation ([30]), equipment selection ([26]), assessment of transportation companies ([31]), seat evaluation considering usability factors ([13]), proposing competitive strategies on Turkish container ports ([5]), model selection for ship management ([6]), docking performance of shipyards ([7]), material selection ([11,12]), teaching assistant selection ([20]), ship design ([4]), selection of renewable energy alternative ([24,22]), concept selection for design ([1]), green supplier selection ([3]), and ergonomic advanced manufacturing technology selection ([34]). These studies have demonstrated the applicability and benefits of FAD especially for solving selection problems in fuzzy environments.

The focus of this paper is to provide a multi attribute decision-making tool for selecting an optimal medical imaging system among various alternatives based on different criteria for a university hospital. Since their performance in diagnosis or treatment has a direct impact on patient prognosis, deciding on a technology can be a serious challenge for health care centers that have MCDM problems. This paper presents three different AD approaches to these problems. AD approaches have become quite popular for MCDM problems in recent years. To our knowledge, this is the first study where FAD approaches are used to evaluate the selection mechanism of medical imaging system in literature. Moreover, we present a new tool adapted from Goren and Kulak [15], which is based on FAD approach in decision process. However, unlike earlier studies focusing on FAD, in this study, risk factors are considered and integrated in the methodology of the approach. From this point of view, this is also the first study considering risk factors in the comparison of medical imaging devices.

The rest of this study is structured as follows: Section 2 reviews AD approaches: FAD, weighted FAD (WFAD), and FAD with risk factors (RFAD); Section 3 presents the applications of each approach in the selection of a tomography device, magnetic resonance device, and ultrasound device; while Section 4 offers conclusions and recommendations for the future.

2. Axiomatic design (AD) approaches

The most important concept in AD is the existence of the design axioms. There are two design axioms, namely, the Independence Axiom that maintains the independence of functional requirements (FRs) and the Information Axiom that minimizes the information content.

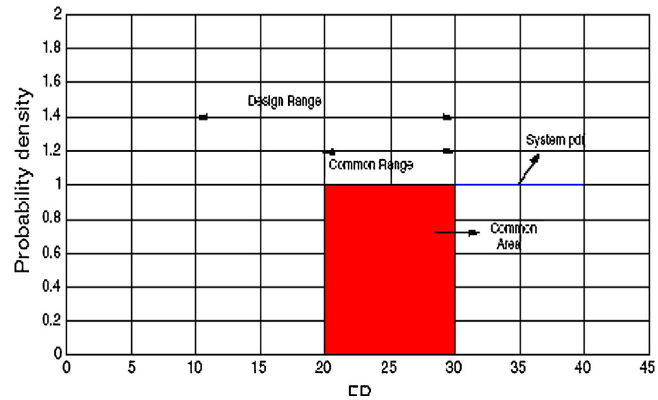

Fig. 1. Design range, system range, common range, and probability density function of a FR ([30,31]).

The Independence Axiom states that the independence of FRs must be maintained. FRs are the minimum set of independent requirements that characterize the design goals.

The Information Axiom states that among the designs that satisfy the Independence Axiom, the design that has the minimum information content is the best design. The Information Axiom defines the information in terms of information content, I_i, which is the probability of satisfying the given FRs. I_i for a given FR_i is defined as follows:

$$I_i = \log_2 \left(\frac{1}{p_i} \right) \quad (1)$$

where p_i is the probability of achieving the functional requirement FR_i and log is the logarithm in base 2. The logarithmic function is chosen so that the information content will be additive when there are many FRs that must be satisfied at the same time. Since there are n FRs, the total information content is the sum of all these probabilities ([42]). For any design, the probability of success of the design depends on what the designer wishes to achieve in terms of tolerance (i.e. design range) and what the system is capable of delivering (i.e. system range). The range between design range and system range is called common range. The acceptable design solution should be within the common range as shown in Fig. 1. In the case of uniform probability distribution function p_i can be calculated as in the following equation:

$$p_i = \left(\frac{\text{Common range}}{\text{System range}} \right) \quad (2)$$

and the information content, I_i is equal to

$$I_i = \log_2 \left(\frac{\text{System range}}{\text{Common range}} \right) \quad (3)$$

The overall information content for each design is calculated and the design with the minimum information content is selected as the most proper alternative. This property of AD approach has been used widely in MCDM problems for comparing alternatives. The main idea of axiomatic design (AD) method for MCDM problems can be explained as follows. AD approach takes into account the design range of each criterion, determined by the decision maker. Thus, the alternative providing the design ranges is selected in AD approach while the alternative meeting the criteria at their best levels is selected in many other methods [30]. The AD approach also differs from many other existing methods from the point of the rejection of an alternative when it does not meet the design range of any criterion [30]. These are important advantages of the AD approach.