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A hybrid SWOT-FANP approach to planning medical equipment replacement

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Abstract

Today, the significance of medical equipment in health and safety of communities cannot be exaggerated. So, all countries need to consider its optimal management because of its significant effect on their development from the perspective of healthcare economics, medical education, and research. In the meantime, annually a significant amount of medical equipment loses its efficiency due to aging, failure, high maintenance costs, and other factors so that it will be unavoidable to replace the equipment effectively. In this regard, given the critical role of the equipment, it is imperative to formulate a strategic and macro program for medical equipment management to replace the available equipment in order to reduce the risk for patients and hospital staff as well as to ensure the availability of services. The present study addressed designing a system of medical equipment replacement using a hybrid SWOT-FANP approach. The approach intends to increase the self-confidence of decision-makers and owners of medical equipment and provide them with adequate supporting evidence and thereby, motivate the formulation of medical equipment replacement strategies selected by the SWOT matrix and with the aid of fuzzy analytic network process (FANP) for their prioritization. The teaching hospitals of a province in Iran were selected as the case study. The applied hybrid approach allows measuring the dependencies of the SWOT factors to consider them in assigning a strategic weight and weights to sub-factors and changing the prioritization of the alternative strategies.

Keywords: Medical equipment management, Medical equipment replacement, Strategic management, SWOT analysis, Fuzzy analytic network process (FANP)

1. Introduction

Today, there is a consensus that ensuring a patient's health requires sound management and use of medical equipment and that the quality of healthcare services depends on the available technologies (Gaetano et al., 2012). Healthcare technology management (HTM) is a major component of healthcare systems (Wang et al., 2006). HTM refers to practices aimed to meet healthcare needs, improve quality, and concurrently, reduce costs. HTM is defined as a systematic process by which healthcare professionals and managers plan and manage healthcare technology assets so as to accomplish the best service quality at the best cost and to have a positive impact on the output of the healthcare sector at the national level by optimizing equipment acquisition and use (Dyro, 2004; Saleh, 2014).

A key facet of the HTM process is medical equipment management (MEM) (Saleh, 2014). MEM is a process that enables hospitals to develop, monitor and manage their equipment so as to make safer, more effective and more economic use of their equipment and keep it in good operational conditions (Dyro, 2004). The MEM process ensures that the risks of the use of medical equipment are minimized (MHRA, 2015). The effectiveness of this process can be assessed against the operational performance of the medical equipment under management (Oliveira et al., 2012). This process is performed within a context of human, material, structural, organizational and financial resources (Saleh, 2014). According to Wang et al. (2006), MEM is a hospital management approach to monitoring medical equipment in the diagnosis, treatment, and monitoring of patients.

Since 2001, the World Health Organization (WHO) has made extensive attempts to formulate and enhance MEM policies and the professionals of WHO have come up with essential recommendations for precise management of medical equipment. In addition to the emphasis on and the support of national regulations on MEM, the WHO notes that it is necessary to formulate national MEM standards (WHO, 2003). In the recent two decades, hospitals in developed countries have launched medical equipment information systems to evaluate the equipment against some key performance indices (Miniati et al., 2013). The main advantages of these information systems are assessing and developing medical equipment technology, fulfilling needs and experiences of their users, making revisions in the design of equipment, and enhancing the potential of the use of medical equipment (Shah & Robinson, 2007). A systemic way for MEM is to study and optimize all steps of the useful life of medical equipment or, in other words, to study the lifecycle of the technology (Porter, 2010). According to MEM lifecycle (Dyro, 2004; Porter, 2010; Taghipour, 2011), the main operational elements to consider in decision-making include 'planning', 'acquisition', 'operation and maintenance', and 'replacement' (Porter, 2010).

Medical equipment replacement is a key pillar of MEM and is regarded as a strategic decision (Rajasekaran, 2005; Ouda & Saleh, 2012). Medical equipment replacement is the process of removing equipment from healthcare centers due to the aging of equipment, its failure, its high operation and maintenance costs, the adoption of newer technology, or other factors, and this process aims to select appropriate equipment at the appropriate time with minimum cost and maximum productivity (Dyro, 2004; Hartman & Tan, 2014; Fan et al., 2014). Healthcare centers are responsible to ensure that their required medical equipment is always available and can be operated effectively and safely. Thus, informed decisions on modifying, renewing and/or replacing equipment require continuous awareness of medical equipment status (Dyro, 2004; MHRA, 2015). The main goal of equipment replacement is to lead an organization towards profit maximization or cost minimization (Kalavathy, 2016). The planned replacement of the equipment can reduce operation and maintenance costs and other overhead (Taghipour, 2011). In other words, the policy in medical equipment replacement is to determine a proper age of replacement for a piece of equipment instead of using it for a long time with higher operation and maintenance costs (Sharma, 2012).

When making a decision about medical equipment replacement, various criteria should be considered. Ouda and Saleh (2012) divided these criteria into three categories: technical criteria including such indicators as useful lifetime ratio, utilization, and downtime; financial criteria that may include service and operating costs; and safety criteria including such factors as hazards/alerts and user errors. Dondelinger (2004) states that equipment that fails more frequently is more likely to be replaced. These failures may arise from age, poor design, user error, or other factors. He argues that a set of subjective factors are involved in equipment replacement decisions varying with the interests and conditions of the organization. According to Ouda et al. (2010), there is a positive correlation between useful life factors and costs in medical equipment replacement decisions in the hospitals of developing countries. Mummolo et al. (2007) introduced the extent of equipment use as the most important criterion in decisions on medical equipment replacement. Rajasekaran (2005) enumerated factors such as technical, safety and financial criteria as the metrics to assess equipment for medical equipment replacement prioritization. Some have referred to the obvious decline of the efficiency of medical equipment in terms of productivity and output quality over time and to the fact that hospitals need to spend more money to maintain older pieces of equipment and need to supply their increasing operation and maintenance costs and thereby, they have concluded that it is obligatory to determine an age for medical equipment replacement because after that age, it is no longer economical to use the equipment (Rajasekaran, 2005; Mummolo et al., 2007; De Figueiredo, 2009; Sloan, 2011). Kelso (2018) states that a major problem of hospitals and healthcare centers is the lack of a formal system authorized for decision-making on repairing or replacing the broken equipment. He points to the need for identifying the dominant patterns that cause the breaking and failure of medical equipment fleet and recommends the adoption of a systematic approach to repairing or making decisions on medical equipment replacement so that this approach can specify a recommended time of equipment repair/replacement by strengthening the self-confidence of decision-makers and equipment owners. Clark (2008) emphasizes that the plan of medical equipment replacement should be integrated and coordinated with the strategic program of the hospital. Capuano (2010) argues that to make rational decisions on medical equipment replacement, in addition to skills, experiences, knowledge, and access to medical equipment database, it is necessary to use assessment processes for the replacement of medical equipment by clinical engineers in the healthcare sector.

Medical institutions need to have a practical plan for medical equipment replacement and use certain standard information for time management to know when to replace old equipment. Acknowledging the dramatic improvements at healthcare and life quality levels of patients in recent years due to healthcare technology innovations, Miniati et al. (2014) have pointed out the key role that planning to correctly supply and replace medical equipment in hospitals plays in keeping the provision of right technologies. Wang et al. (2006) stress out the necessity of continuous examination and improvement of management strategies of healthcare organization with respect to equipment technology enhancement.

Replacement decisions have critical and extensive implications during the lifespan of an organization. They seem especially vital when it comes to complicated modelers like medical equipment replacement. Healthcare institutions are constantly engaged with these decisions. It is vital for budget management to have an optimal plan for replacement, maintenance, and operational costs. According to Taylor and Jackson (2005), a medical equipment replacement program looks for financing to replace the prioritized high-risk medical equipment. Oliveira (2012) suggests that a medical equipment replacement program is a strategic plan aimed at replacing available equipment to reduce the risk for patients and staff of a hospital and to ensure continuous availability of services in urban and rural areas.

Hospitals and healthcare centers always need to replace old technologies that are no longer cost-effective, have no clinical applications, or may be obsolete. Most hospitals lack enough investing funds to approve all requests for equipment replacement. Decisions to replace technologies that are not technical, standard and/or performance-based are usually made through a capital planning process. These decisions are usually based on subjective or narrative reasons, not first-hand information, experience, or scientific analysis (Rajasekaran, 2005). Medical equipment is often replaced when it fails at critical conditions or when it is found out during its service time that the parts and manufacturer support are not available (Taghipour, 2011; Saleh, 2014). It is occasionally observed that as soon as new technologies are made available, the equipment is replaced even if it is still effective (Clark, 2008). Consequently, injudicious costs to replace equipment that can still work instead of focusing on equipment that needs to be replaced impair the overall productivity of the healthcare system drastically (Mkalaf, 2015). To avoid wastage and overhead costs in hospitals, it should be ensured that medical equipment is replaced in a rational and planned manner.

Given the facts that medical equipment performance in hospitals is vital to guarantee patient safety along with the main mission of hospitals and that the poor performance of this section and inattention to its vital components can cause hospitals to fail or display ineffective performance (Vellani, 2006), it is imperative to manage medical equipment and consider the process of MEM and its sound implementation in hospitals. Thus, hospitals need to develop a systematic process for medical equipment replacement and revise it on a regular basis. Medical equipment replacement should not be a political process or involuntary response to unrelated phenomena. As long as a well-considered system is not developed resting upon explicit reports on medical replacement requirements and priorities, replacement requests will be person-dependent and unplanned. Equipment replacement plan is closely related to the overall strategic plan of an organization or system (Clark, 2008; Ouda & Saleh, 2012). The strategic plan encompassing clinical and non-clinical factors shows the organizational orientation of a healthcare system. We may need technologies to provide new services that are unique to our organization, or a change in paradigm may be happening in the healthcare sector towards a distinct technological style. Therefore, it seems necessary to have a systematic method to prioritize the replacement of all medical equipment so that limited resources can be utilized in the best possible way. An ideal plan for healthcare technology replacement should be at the level of whole system and should cover all clinical equipment. In this regard, precise and objective data should be used in analyses, and the developed plan should be flexible enough to use non-equipment factors. Chien et al. (2010) suggest that medical equipment should be replaced in accordance with optimal strategies. To plan such procurement, a medical equipment replacement decision system should be in place to enable the effective management of the limited organizational resources. The present study aims to present a hybrid SWOT-FANP approach to formulating medical equipment replacement strategies in the studied hospitals so that it can be used by hospitals and healthcare centers for the planning of medical equipment replacement through a decision system.

Optimal management of medical equipment in hospitals plays a significant role in reducing costs and providing optimal healthcare services. A review of the literature shows that few studies have proposed techniques for medical equipment replacement decisions and most proposed techniques (Taylor & Jackson, 2005; Mummolo et al., 2007; Capuano, 2010; Ouda et al., 2010; Sloan, 2011; Miniati et al., 2014; Jamshidi et al., 2015; Faisal & Sharawi, 2015; Kelso, 2018) have considered only a few factors. As well, none of the studies have used our proposed research model. A review of the studied in Iran reveals that hospitals in Iran are suffering from the lack of a systematic method of planning medical equipment replacement. In addition, no experimental and systematic study has focused on medical equipment replacement in Iran and the few studies in this respect have just briefly discussed the basic concept and its significance in the lifecycle of medical equipment management based on the research conducted in other parts of the world. So, the present study aims to identify the criteria influencing medical equipment replacement in hospitals and healthcare centers of Iran and to devise a decision system for efficient replacement of medical equipment so that one can have a strategic view on medical equipment replacement decisions and make an organized attempt based on the principles of strategic management to make fundamental decisions and take fundamental actions in this respect.

To accomplish their goals and missions, organizations are struggling with various challenges and opportunities. To tackle these challenges and exploit environmental opportunities, organizations have appealed to the use of strategic management as an efficient framework to improve their position in the world of rapid environmental changes (Porter, 1996; Bryson, 2015). Strategic management refers to a set of decisions and actions that are taken by the organization management with the consultation of all organizational levels and dictate the long-term activities of the organization (Wheelen & Hunger, 2010; David & David, 2016). Strategic management is an organized effort to make fundamental decisions and take fundamental actions that shape an organization and the orientation of its activities versus other institutions within a legal framework (Vishnevskiy et al., 2016). Strategic management does not have a static nature; strategic models often encompass a feedback loop to monitor their implementation and inform the next round of planning (Hill & Jones, 2012). Organizations use diverse processes to formulate and operate their strategic management activities. Organizations with an advanced planning system can formulate more detailed processes (Bagheri, 2016). Strategic management process is meant achieving a preliminary agreement on the form and content of the strategic management system so as to foster support and commitment in key decision-makers and leaders of the industry in question (Rosenzweig, 2015). In general, a strategic management process is composed of three basic levels: strategy formulation, implementation, and control and assessment (Hax & Majluf, 1991; David & David, 2016).

As the first step of strategic management, strategy formulation is a purposeful instrument to create a competitive advantage for an organization and, consequently, improve its performance

(Wang et al., 2014). Strategy formulation refers to a process by which an organization defines its operating domain and long-term orientation. This process includes the planning of a path by which the organization is led to value creation by shaping its activities and resources within the environment in which it works (Porter, 1996; Bisbe & Malagueno, 2012). Strategy formulation is perceived as the process of strategy selection and prioritization. This process is a key factor for the success of an organization because it provides a framework within which the organization can realize its predicted results (Wheelen & Hunger, 2010).

All organizations are faced with a set of internal and external forces that can, on the one hand, be potential incentives, or on the other hand, be subject to potential constraints with respect to the organizational performance and/or the goals the organization seeks to reach (Houben et al., 1999). It is, therefore, imperative to perform a comprehensive analysis of an organization's internal and external environment and, at the first level, on the strategic management process (Yuan, 2013). In a strategic management process, diverse methods and techniques may be used to analyze strategic issues (Yuksel & Dagdeviren, 2007). One of these tools that is employed to analyze internal and external strategic issues during strategy formulation is SWOT matrix or analysis, which assesses the strengths, weaknesses, opportunities, and threats of an organization. SWOT analysis is an important decision support tool usually used to systematically analyze an organization's internal and external environment (Shafieyan et al., 2017). SWOT analysis can be applied to any product, location, industry, or organization (Ghorbani et al., 2015). Despite extensive applications of SWOT analysis, it has several limitations such as the inability to rank criteria and strategies (Lin et al., 2008) and this specific limitation hinders its use in the comprehensive assessment of a strategic decision-making process (Yuksel & Dagdeviren, 2007; Lee, 2013). In this respect, it is functional to use multiple attribute decision making (MADM) models, which are major tools to rank options in multidimensional and complicated problems. Various methods have already been proposed to rank options in the context of the MADM models (Patil & Kant, 2014; Kilic et al., 2015; Arsic et al., 2017; Deveci et al., 2018; Wu et al., 2018; Ervural et al., 2018).

The present study is the first attempt in Iran to identify the key criteria underpinning medical equipment replacement in the studied hospitals and to provide a coherent program to plan medical equipment replacement. It is, thereby, intended to optimally use existing resources to enhance self-reliance and self-regulation of the MEM process and to minimize the adverse impacts of inattention to this key stage in the MEM cycle. During the review of the literature, we found several studies that have applied qualitative, quantitative or mixed techniques and approaches to provide a system or model for MEM or its different steps. Examples include fault tree analysis (FTA) method (Ouda et al., 2010), quality function development (QFD) technique (Saleh, 2014), fuzzy approach (Mummolo et al., 2007), genetic algorithm (Fan et al., 2014), Markov decision process (Dehayem Nodem et al., 2011; Sloan, 2011), and others used to analyze MEM. Some research has, also, employed AHP technique to rank indices (Bahadori et al., 2012; Jamshidi et al., 2015; Faisal & Sharawi, 2015).

The present study has used the ANP technique as an enhanced AHP technique that gives more precise results for complicated problems. This technique can be applied to complicated problems with a non-categorical structure. A main advantage of the ANP technique is that it allows for considering the bilateral relationships of different decision levels with one another and the interrelationships of decision criteria at the same level. Horenbeek and Pintelon (2014)'s study is one of the few works in which the ANP technique has been employed. Also, the present study used linguistic values and their fuzzy equivalent to assign weights to possible criteria and subcriteria and assess the options. By using the fuzzy ANP technique, the present study tries to take advantage of the ANP technique and combine it with a fuzzy approach to tackle the problem of the lack of precise and comprehensive input information. The proposed hybrid approach can be applied as a programming tool to select replacement strategies for medical equipment. The significance of the study lies in the facts that first, it tries to fill the research gap in medical equipment replacement programming by SWOT analysis and fuzzy ANP technique and second, it allows researchers, experts, hospital managers, and policymakers of this sector both to get acquainted with the technique of strategy selection by the hybrid approach used in the present study and to consider the criteria, strategies, weight values, and their ranking and make use of them if possible. The present study aims at using a hybrid SWOT-FANP approach to provide a decision system for medical equipment replacement planning.

The paper is organized as below. Section 2 briefly introduces the method components of our hybrid approach. Section 3 presents the proposed FANP framework for SWOT. Section 4 describes the steps to implement the SWOT-FANP approach. Results are discussed in Section 5, and the paper is concluded in Section 6 with some recommendations.

2. An overview of the methods employed

The present work employs the SWOT analysis to enumerate all related sub-factors and categorized them into strengths (S), weaknesses (W), opportunities (O), and threats (T) from internal and external perspectives. Also, an FANP approach is used for weight assignment to the individual SWOT factors and sub-factors. These two methods are briefly described below.

2.1 SWOT analysis

SWOT analysis summarizes the most important internal and external factors that may influence the future of an organization, or the so-called strategic factors (Yuksel & Dagdeviren, 2007). Internal and external factors include variables that are formed inside and outside an organization and the management has no short-term impact on any of them (Houben et al., 1999). SWOT analysis considers the strengths and weaknesses of an organization as the internal factors and the threats and opportunities as the external factors. The strategies are specified and formulated using these factors by matching key internal and external factors. A SWOT analysis determines the best compound strategies to maximize strengths and opportunities and minimize threats and weaknesses (Hong & Chan, 2010). The derived information can be systematically displayed in a matrix (Table 1).

		Internal Factors	
		Strengths (S)	Weaknesses (W)
External Factors	Opportunities (O)	SO strategy	WO strategy
	Threats (T)	ST strategy	WT strategy

Table 1. SWOT analysis matrix

Different combinations of the four factors of the matrix can be employed to find a long-term strategy (Houben et al., 1999). Strengths-opportunities (SO) strategies use the internal strengths of an organization to take advantage of external opportunities; weaknesses-opportunities (WO) strategies exploit external opportunities to improve internal weaknesses; strengths-threats (ST) strategies aim at using an organization’s strengths to hinder or minimize the impact of external threats; and finally, weaknesses-threats (WT) strategies are defensive tactics to reduce internal weaknesses and avoid external threats (David, 2007). Here, internal factors (strengths and weaknesses) refer to the factors that hospitals can control and change them, and external factors (opportunities and threats) refer to the factors that are out of the control of hospitals. As already mentioned, the ANP technique is used below to quantify the results of the SWOT matrix.

2.2 The Analytic Network Process (ANP) method

Analytical hierarchy process (AHP) is a robust technique that helps analysts pick the best decision across numerous decisions by portraying a decision-making problem in a hierarchical structure with different levels (Saaty, 1996). The AHP technique allows assessing factors that are considered as criteria, as well as options, by allocating relative weights to them (Sevkli et al., 2012). The technique posits that the factors represented in the hierarchical structure are independent and there can only be unilateral relationships between the elements of different levels of decision-making in the hierarchy and between the elements within one cluster and across the clusters (Chung et al., 2005). But, this assumption is not always rational. The AHP method is not appropriate for models in which there are interdependencies between the clusters or inner dependencies between the elements of one cluster (Yuksel & Dagdeviren, 2007; Lin et al., 2008). To tackle this drawback, the analytic network process (ANP) has been presented.

ANP method is an extension of the AHP (Saaty, 1996). It is usually impossible to represent very complicated problems in a unidirectional hierarchical structure as it cannot capture the complicated and multi-dimensional relationships between alternatives and criteria. The same drawback is observed in ANP, which determines all of the elements and relationships as one way, two-way interactions and loops. Figure 1 depicts structural differences between a hierarchy and a network (Yuksel & Dagdeviren, 2007). In ANP, the pairwise comparison process is expanded to judging each component by including priorities of criteria and alternatives. The ANP model comprises of four main parts (Chung et al., 2005; Yuksel & Dagdeviren, 2007). The first part is related to defining problem comprehensively within a network model.

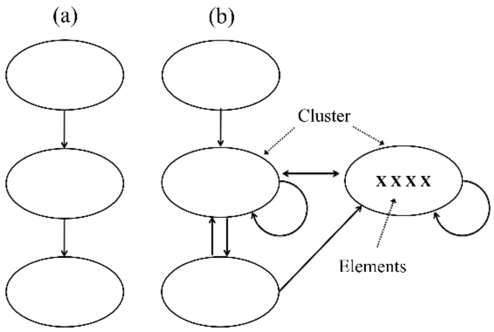

Figure 1. The structural difference between a hierarchy and a network: (a) a hierarchy; (b) a network

The second part involves the establishment of pairwise comparison matrices and priority vectors. Like comparisons made in AHP, pairs of decision elements in each cluster are compared in terms of their importance determined by their controlling criteria. Clusters are, also, compared on a pairwise basis with respect to their contribution to the goal (Meade & Sarkis, 1999). Furthermore, the elements of a cluster should also be checked in pairs in terms of interdependencies; the effect of each element on other elements can be displayed by an eigenvector. The relevant major weights are assigned on a scale of 1-9 (Table 2) according to Saaty (1980)'s definition.

In Table 2, score 1 represents equal importance of two elements and score 9 shows higher importance of an element (a row in matrix) than the other element (a column in matrix). The reverse comparison is assigned with a reciprocal value that is equal to $a_{ij} = 1/a_{ij}$ in which $a_{ij}(a_{ji})$ represents the *i*th (*j*th) importance of the element (Meade & Sarkis, 1999)

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate values

Table 2. Saaty's 1–9 scale for AHP and ANP preference

Like AHP, pairwise comparisons in ANP are conducted within a matrix. By solving Eq. (1), a relative importance vector can be obtained as the estimation of the relative importance associated with the comparison of elements (or clusters).

$$A \times w = \lambda_{max} \times w \quad (1)$$

in which A is pairwise comparison matrices, w is eigenvector, and λ_{max} is the largest eigenvalue of matrix A. Saaty (1980) proposed several algorithms to approximate w.

The third part is to construct a supermatrix to show priorities of elements. To build a supermatrix, local priority vectors are placed in appropriate columns of a matrix so as to obtain global priorities in a system with interdependent influences (Saaty, 1996). A supermatrix is, indeed, a partitioned matrix where each section of the matrix represents a relationship between two clusters in a system (Yuksel & Dagdeviren, 2007).

The last part is to make decisions according to the supermatrix model. If the supermatrix that is formed in the third step covers the whole network, the weights of alternatives can be found in the columns of normal supermatrix alternatives. The alternative with the highest global priority should be chosen as the best option. This is performed by calculations using matrix operations. Not only is the ANP technique used to prioritize decision indices but it can also be applied in prioritizing final options (Yuksel & Dagdeviren, 2007).

The fuzzy ANP (FANP) method

The discrete scale of Saaty, presented in Table 2, is precise and crisp. But, human judgments are often uncertain and ambiguous. Therefore, fuzziness should be incorporated into modeling (Lee, 2013). Furthermore, the matching and mapping of judgments as a single number cannot be explained with definite numbers. Thus, the fuzzy ANP (FANP) method is proposed for these issues (Sevkli et al, 2012; Arsic et al., 2017). So, instead of Saaty's discrete scale of 1-9, a triangular fuzzy number (TFN) scale of $\tilde{1}-\tilde{9}$ (Onut et al., 2009), as presented in Table 3, can be employed.

(TFN)	Linguistic scale for importance	Triangular fuzzy scale
$\tilde{1}$	Equally preferred	(1, 1, 1)
$\tilde{2}$	Equally to moderately preferred	(1, 2, 3)
$\tilde{3}$	Moderately preferred	(2, 3, 4)
$\tilde{4}$	Moderately to strongly preferred	(3, 4, 5)
$\tilde{5}$	Strongly preferred	(4, 5, 6)
$\tilde{6}$	Strongly to very strongly preferred	(5, 6, 7)
$\tilde{7}$	Very strongly preferred	(6, 7, 8)
$\tilde{8}$	Very strongly to extremely preferred	(7, 8, 9)
$\tilde{9}$	Extremely preferred	(8, 9, 10)

Table 3. The linguistic scale of TFN

To assess the judgments of a decision-maker, pairwise comparison matrices are built by triangular fuzzy numbers in Table 3. This fuzzy comparison matrix can be denoted as Eq. (2) (Ramik, 2007).

$$= \begin{bmatrix} (a_{11}^l, a_{11}^m, a_{11}^u) & (a_{12}^l, a_{12}^m, a_{12}^u) & \cdots & (a_{1n}^l, a_{1n}^m, a_{1n}^u) \\ (a_{21}^l, a_{21}^m, a_{21}^u) & (a_{22}^l, a_{22}^m, a_{22}^u) & \cdots & (a_{2n}^l, a_{2n}^m, a_{2n}^u) \\ \vdots & \vdots & \ddots & \vdots \\ (a_{m1}^l, a_{m1}^m, a_{m1}^u) & (a_{m2}^l, a_{m2}^m, a_{m2}^u) & \cdots & (a_{mn}^l, a_{mn}^m, a_{mn}^u) \end{bmatrix}$$

in which the element $\tilde{a}_{mn}$ that is obtained by $(a_{mn}^l, a_{mn}^m, a_{mn}^u)$ shows the comparison of the component *m* with component *n*. Due to the operational rules of fuzzy numbers (Wang & Chang, 2007), the matrix $\tilde{A}$ can be rewritten as Eq. (3) by replacing $\tilde{a}_{mn}$ with its equivalent reciprocal values (i.e. $1/\tilde{a}_{mn}$) (Tuzkaya & Onut, 2008).

$$\tilde{A} = \begin{bmatrix} (1,1,1) & (a_{12}^l, a_{12}^m, a_{12}^u) & \cdots & (a_{1n}^l, a_{1n}^m, a_{1n}^u) \\ \left(\frac{1}{a_{21}^u}, \frac{1}{a_{21}^m}, \frac{1}{a_{21}^l}\right) & (1,1,1) & \cdots & (a_{2n}^l, a_{2n}^m, a_{2n}^u) \\ \vdots & \vdots & \ddots & \vdots \\ \left(\frac{1}{a_{m1}^u}, \frac{1}{a_{m1}^m}, \frac{1}{a_{m1}^l}\right) & \left(\frac{1}{a_{m2}^u}, \frac{1}{a_{m2}^m}, \frac{1}{a_{m2}^l}\right) & \cdots & (1,1,1) \end{bmatrix}$$

$\tilde{A}$ is a triangular fuzzy comparison matrix to estimate the fuzzy priority $\widetilde{w}_i$ in which $\widetilde{w}_i = (w_i^l, w_i^m, w_i^u), i = 1, 2, \ldots, n$ by a judgment matrix that approximates the fuzzy ratios $\tilde{a}_{ij}$ so that we have $\tilde{a}_{ij} \approx \widetilde{w}_i / \widetilde{w}_j$. There are several methods to make estimations of fuzzy priorities. The logarithmic least square method is the most efficient (Sevkli et al., 2012). We use it here. By this technique, triangular fuzzy weights can be calculated for the relative importance of factors, factor feedbacks, and options according to individual factors. Triangular fuzzy numbers are obtained by the logarithmic least square methods presented in Eq. (4) and (5) (Onut et al., 2009).

$$\widetilde{w}_k = (w_k^l, w_k^m, w_k^u), \quad k = 1, 2, \ldots, n \tag{4}$$

$$w_k^s = \frac{\left(\prod_{j=1}^{n} a_{ij}^s\right)^{1/n}}{\sum_{k=1}^{n}\left(\prod_{j=1}^{n} a_{ij}^m\right)^{1/n}} \quad s \in \{l, m, u\} \tag{5}$$

Then, the weights of options should be converted into a crisp number and accordingly, the strategic options should be prioritized.

In the present paper, the SWOT analysis is performed by fuzzy analytic network process (FANP) that allows for measuring the interdependences of SWOT factors in addition to ranking SWOT factors, SWOT sub-factors, and strategic options.

3.0 The Proposed FANP Framework for SWOT

The hierarchy and network model used for the SWOT analysis of the present study is shown in Figure 2. This model, first proposed by Yuksel and Dagdeviren (2007), is composed of four levels. Goal (prioritizing alternative strategies) is represented in the first level followed by main criteria (SWOT factors) and sub-criteria (SWOT sub-factors) in the second and third levels, respectively and the last level including alternatives (alternative strategies). The SWOT hierarchical supermatrix with four levels is as below.

$$W = \begin{matrix} \text{Goal} \\ \text{SWOT factors} \\ \text{SWOT sub}-\text{factors} \\ \text{Alternatives} \end{matrix} \begin{bmatrix} 0 & 0 & 0 & 0 \\ \mathbf{w_{21}} & 0 & 0 & 0 \\ 0 & \mathbf{W_{32}} & 0 & 0 \\ 0 & 0 & \mathbf{W_{43}} & \mathbf{I} \end{bmatrix} \tag{6}$$

in which w_{21} is a vector that shows the effect of goal on criteria, W_{32} is a matrix that shows the effect of criteria on individual sub-criteria, W_{43} is a matrix that shows the effect of sub-criteria on individual alternatives, and I is a unit matrix.

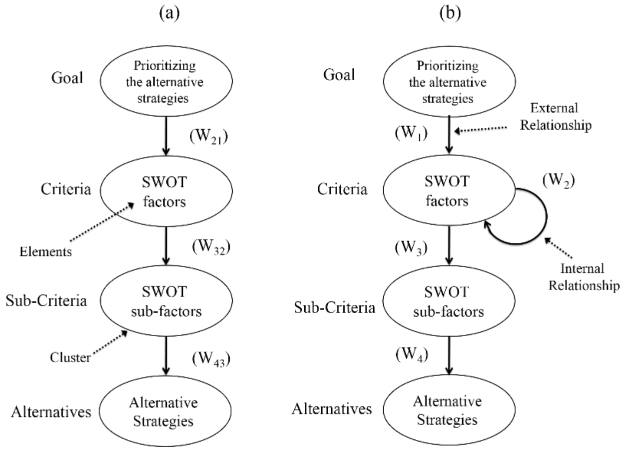

Figure 2. (a) The hierarchical representation of the SWOT model. (b) The network representation of the SWOT model

Figure 2a is a hierarchical representation of the SWOT model and Figure 2b is a network representation of its overall network. The network model presents a case of hierarchy with the inner dependence of clusters, but no feedback is shown. Here, SWOT factors, sub-factors, and strategies have been used instead of criteria, sub-criteria, and alternatives, respectively and the SWOT factors have internal relationships.

The main steps of the research can be summarized as below. The first step is to identify SWOT factors, sub-factors, and alternatives. The importance of the SWOT factors, which is related to the first step of the concept of matrix transformation in ANP, is determined according to Lee and Kim (2000). Then, the inner dependence matrix, the weights of the SWOT sub-factors, and the priority vectors for alternative strategies based on the SWOT sub-factors are determined according to the inner dependences of the SWOT factors.

Letters in parentheses in Figure 2b represent the relationship that is argued by the sub-matrix to assess the supermatrix from relative importance weights. According to the schematic representation of Figure 2b, the notation of the general sub-matrix for the SWOT model of the present study is as below.

$$\widetilde{W} = \begin{matrix} \text{Goal} \\ \text{SWOT factors} \\ \text{SWOT sub}-\text{factors} \\ \text{Alternatives} \end{matrix} \begin{bmatrix} 0 & 0 & 0 & 0 \\ \widetilde{\mathbf{w}}_1 & \widetilde{\mathbf{W}}_2 & 0 & 0 \\ 0 & \widetilde{\mathbf{W}}_3 & 0 & 0 \\ 0 & 0 & \widetilde{\mathbf{W}}_4 & \mathbf{I} \end{bmatrix} \quad (7)$$

in which $\widetilde{w}_1$ is a fuzzy vector showing the impact of goal, i.e. the prioritization of strategies in terms of the SWOT factors, $\widetilde{W}_2$ is a fuzzy matrix showing the inner dependence of the SWOT factors, $\widetilde{W}_3$ is a fuzzy matrix representing the impact of the SWOT factor on each SWOT sub-factor, and $\widetilde{W}_4$ is a fuzzy matrix indicating the impact of the SWOT sub-factors on each alternative. The following is the framework of the study to apply ANP in the operation matrix to prioritize the replacement strategies that have been specified by the SWOT analysis (Sevkli et al, 2012; Arsic et al., 2017).

- **Step 1:** The SWOT sub-factors are identified and the alternative strategies (medical equipment replacement strategies) are determined according to the SWOT sub-factors. Then, the network model is built.
- **Step 2:** It is assumed that there is no dependence between the SWOT factors. The importance degrees of the SWOT factors are determined on a 9-point scale (for example, we calculate $\widetilde{w}_1$).
- **Step 3:** The matrix of the inner dependence of the SWOT factors is determined on a fuzzy scale of $\tilde{1} - \tilde{9}$ with respect to the other factors and using the schematic representation of the inner dependence of the SWOT factors (for example, we calculate $\widetilde{W}_2$).
- **Step 4:** Priorities that are inter-depended on the SWOT factors are determined (for example we calculate $\widetilde{w}_{factors} = \widetilde{W}_2 \times \widetilde{w}_1$).
- **Step 5:** Local importance degrees of the SWOT sub-factors are determined on a fuzzy scale of $\tilde{1} - \tilde{9}$ (for example, we calculate $\widetilde{w}_{sub-factors(local)}$).
- **Step 6:** Global importance degrees of the SWOT sub-factors are determined (for example, $\widetilde{w}_{sub-factors(global)} = \widetilde{w}_{factors} \times \widetilde{w}_{sub-factors(local)}$).
- **Step 7:** The importance degrees of the alternative strategies are determined on a fuzzy scale of $\tilde{1} - \tilde{9}$ with respect to each SWOT sub-factor (For example, we calculate $\widetilde{W}_4$).
- **Step 8:** The overall priorities of the alternative strategies that reflect the interdependence of the SWOT factors are determined (for example, $\widetilde{w}_{alternatives} = \widetilde{W}_4 \times \widetilde{w}_{sub-factor(global)}$).
- **Step 9:** The overall fuzzy prioritization of the alternative strategies is converted to crisp numbers.

4.0 Steps to Implement the SWOT-FANP Approach

To select and prioritize medical equipment replacement strategies using the proposed SWOT-FANP methodology, this section presents a case study to implement the methodology in teaching hospitals of Guilan province in Northern Iran. In this section, after the research data were collected, the SWOT and FANP analyses were performed to check the feasibility of formulating a medical equipment replacement program for the teaching hospitals of Guilan province (12 hospitals) by analyzing the results and determining the priorities. The approach derived from this analysis as a decision system to formulate medical equipment replacement strategies can pave the way for the formulation of effective strategies to attain a systemic plan.

Step 1. After consultation with the expert teams of each hospital and collecting their opinions, 10 key internal factors (five strengths and five weaknesses) and 10 key external factors (five opportunities and five threats) were identified as the factors influencing medical equipment replacement in the studied region. Then, after examining these factors and specifying their relationships, eight types of strategies that can be applied for the effective replacement of medical equipment in the studied hospitals were adopted. As the SWOT matrix in Table 4 shows, eight key strategies were identified for the replacement of medical equipment in the teaching hospitals of Guilan province by pairwise comparison of strengths, weaknesses, opportunities, and threats.

		Strengths (S)	Weaknesses (W)
		S1. The training of medical equipment operators by hospitals **S2**. The presence of supporting technical and executive rules and regulations for optimal MER in hospitals **S3**. Doctors' request for the replacement of the present equipment with modern technologies **S4**. Timely replacement of equipment with respect to the signs of finished useful life **S5**. The presence of a comprehensive information system for MER in hospitals	**W1**. High age of medical equipment **W2**. The failure of hospitals to supply high MER costs **W3**. Additional costs of delayed MER **W4**. Failure of hospitals in access to advanced medical technologies **W5**. The lack of allocation of budget to supply medical equipment by hospitals
Opportunities (O)	**O1**. Higher demand for modern medical services in the province **O2**. Possibility of increasing medical service value by enhancing medical equipment quality **O3**. Potential for producing and developing some medical equipment in Iran **O4**. Retailers' guarantee for free replacement and/or repair of equipment **O5**. Exemptions and economic supports of state to import required medical equipment	**SO strategies:** **SO1**: Promoting the quality of current equipment and their replacement with modern technologies to provide new services with respect to the supporting executive regulations for MER **SO2**: The replacement of the current equipment at the end of the lifetime with high-quality equipment of reliable manufacturers with respect to the comprehensive MER plan and the signs of the finished useful lifetime of the equipment	**WO strategies:** **WO1**: Absorbing credit to purchase or replace medical equipment with respect to the support of the state and private sector interested in investment **WO2**: The supply of medical equipment from domestic manufacturers as much as possible to enjoy specific facilities

Threats (T)	**T1**. Unavailability of spare parts for equipment **T2**. Poor supports of medical equipment manufacturers/retailers **T3**. High maintenance costs **T4**. Financial loss due to the downtime of the failed equipment **T5**. Messy market and severe fluctuations in the medical equipment market	**ST strategies:** **ST1**: The use of supporting technical and executive regulations of the state to attract local investors to finance MER costs in hospitals **ST2**: Formulation and optimal implementation of a comprehensive hospital-specific plan of maintenance and MER to reduce financial losses due to the downtime of failed equipment and to reduce high maintenance costs	**WT strategies:** **WT1**: Establishing a technical workgroup for MER in hospitals to monitor the implementation of MER plan and the selection of the sustainable supplier of equipment **WT2**: Planning and implementation of effective mechanisms to reduce MER costs and finance the purchase of new equipment

Table 4. The SWOT matrix of medical equipment replacement (MER) strategies in the teaching hospitals of Guilan province

Then, the problem is converted into a network structure so as to make it possible to measure the sub-factors and alternative strategies by the ANP method. Figure 3 depicts this network representation. Achieving 'prioritization of alternative strategies, or medical equipment replacement strategies' is the first level of the FANP model and the SWOT factors (strengths, weaknesses, opportunities, and threats) compose the second level. The SWOT sub-factors in the third level are composed of five sub-factors for strengths, five sub-factors for weaknesses, five sub-factors for opportunities, and five sub-factors for threats. Eight alternative strategies are developed for the research and they are presented in the last level. The strategies are prioritized by the FANP approach in the next steps.

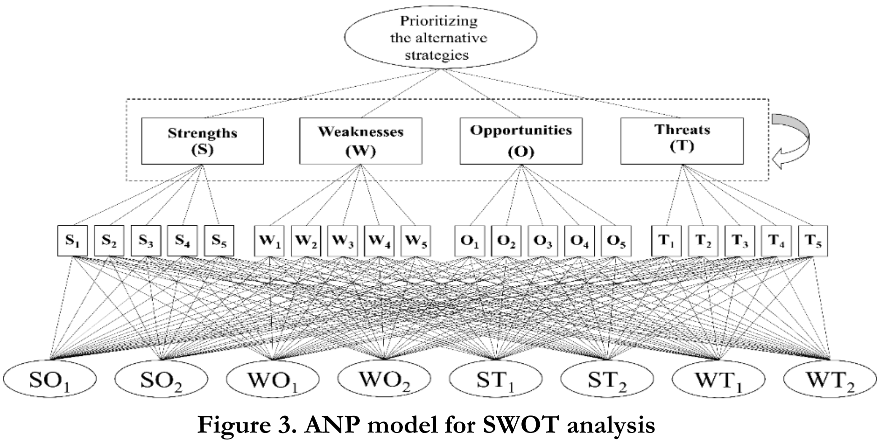

Figure 3. ANP model for SWOT analysis

Step 2. Assuming the lack of any dependencies among the SWOT factors and given the goal, pairwise comparisons are performed between the factors on a fuzzy scale of $\tilde{1} - \tilde{9}$. The results of the comparison are given in Table 5. All pairwise comparisons about the applications were made by the expert teams of the hospitals separately. After all matrices were collected, the geometric average of the relevant fuzzy matrices was calculated to build unit matrices. The fuzzy pairwise comparison matrix in Table 5 (and other matrices of this chapter) was analyzed by Microsoft Excel and the derived eigenvectors were presented. It should be noted that the importance weights of all fuzzy pairwise comparison matrices are normalized.

SWOT factors	S	W	O	T	Importance degrees of SWOT factors
S	(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(2, 3, 4)	(0.203, 0.419, 0.813)
W		(1, 1, 1)	(1, 2, 3)	(2, 3, 4)	(0.146, 0.302, 0.610)
O			(1, 1, 1)	(1, 2, 3)	(0.087, 0.178, 0.372)
T				(1, 1, 1)	(0.062, 0.101, 0.203)

Table 5. Pairwise comparison of SWOT factors by assuming that there is no dependence among

As specified in Table 5, the fuzzy importance vector of the SWOT factors can be summarized as Eq. (8).

Step 3. The inner dependence of the SWOT factors has been determined by pairwise comparisons and analysis of the impact of the factors on one another. As already mentioned, it is not always possible to assume the independence of all SWOT factors. The simultaneous use of

$$\tilde{w}_1 = \begin{bmatrix} S \\ W \\ O \\ T \end{bmatrix} = \begin{bmatrix} 0.203 & 0.419 & 0.813 \\ 0.147 & 0.302 & 0.610 \\ 0.087 & 0.178 & 0.373 \\ 0.062 & 0.101 & 0.203 \end{bmatrix} \quad (8)$$

The SWOT analysis and ANP method may give more appropriate and realistic results. By analyzing the internal and external environment of the studied hospitals, the dependence of the SWOT factors illustrated schematically in Figure 4 can be determined.

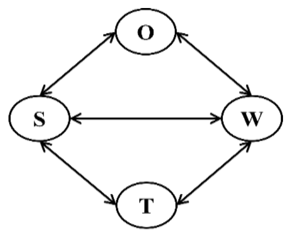

Figure 4. Inner dependence among SWOT factors

According to the inner dependencies shown in Figure 4, Tables 6-9 present the fuzzy matrix of the inner dependence of the SWOT factors with respect to individual factors. The eigenvectors (relative importance weights) are shown in the last column of Tables 6-9. The inner dependence fuzzy matrix of the SWOT factors ($\widetilde{W}_2$) that has been calculated by relative importance weight is depicted by Eq. (9).

Strengths	W	O	T	Relative importance weights
W	(1, 1, 1)	(0.142, 0.166, 0.20)	(0.25, 0.333, 0.50)	(0.072, 0.095, 0.134)
O		(1, 1, 1)	(2, 3, 4)	(0.416, 0.632, 0.949)
T			(1, 1, 1)	(0.169, 0.273, 0.435)

Table 6. The inner dependence matrix of the SWOT factors with respect to "Strengths"

Weaknesses	S	O	T	Relative importance weights
S	(1, 1, 1)	(2, 3, 4)	(5, 6, 7)	(0.416, 0.632, 0.949)
O		(1, 1, 1)	(2, 3, 4)	(0.169, 0.273, 0.435)
T			(1, 1, 1)	(0.072, 0.095, 0.134)

Table 7. The inner dependence matrix of the SWOT factors with respect to "Weaknesses"

Opportunities	S	W	Relative importance weights
S	(1, 1, 1)	(5, 6, 7)	(0.652, 0.857, 1.120)
W		(1, 1, 1)	(0.124, 0.143, 0.168)

Table 8. The inner dependence matrix of the SWOT factors with respect to "Opportunities"

Threats	S	W	Relative importance weights
S	(1, 1, 1)	(4, 5, 6)	(0.606, 0.833, 1.135)
W		(1, 1, 1)	(0.141, 0.167, 0.202)

Table 9. The inner dependence matrix of the SWOT factors with respect to "Threats"

$$\widetilde{W}_2 = \begin{bmatrix} L & M & U & L & M & U & L & M & U & L & M & U \\ 1.000 & 1.000 & 1.000 & 0.416 & 0.632 & 0.949 & 0.652 & 0.857 & 1.120 & 0.606 & 0.8\ 3 & 1.135 \\ 0.072 & 0.095 & 0.134 & 1.000 & 1.000 & 1.000 & 0.124 & 0.143 & 0.168 & 0.141 & 0.167 & 0.202 \\ 0.416 & 0.632 & 0.949 & 0.169 & 0.273 & 0.435 & 1.000 & 1.000 & 1.000 & 0.000 & 0.000 & 0.000 \\ 0.169 & 0.273 & 0.435 & 0.072 & 0.095 & 0.134 & 0.000 & 0.000 & 0.000 & 1.000 & 1.000 & 1.000 \end{bmatrix} \quad (9)$$

Step 4. At this step, the cross priorities of the SWOT factors have been calculated by Eq. (10).

$$\widetilde{w}_{factors} = \widetilde{W}_2 \times \widetilde{w}_1 \quad (10)$$

$$= \begin{bmatrix} L & M & U & L & M & U & L & M & U & L & M & U \\ 1.000 & 1.000 & 1.000 & 0.416 & 0.632 & 0.949 & 0.652 & 0.857 & 1.120 & 0.606 & 0.833 & 1.135 \\ 0.072 & 0.095 & 0.134 & 1.000 & 1.000 & 1.000 & 0.124 & 0.143 & 0.168 & 0.141 & 0.167 & 0.202 \\ 0.416 & 0.632 & 0.949 & 0.169 & 0.273 & 0.435 & 1.000 & 1.000 & 1.000 & 0.000 & 0.000 & 0.000 \\ 0.169 & 0.273 & 0.435 & 0.072 & 0.095 & 0.134 & 0.000 & 0.000 & 0.000 & 1.000 & 1.000 & 1.000 \end{bmatrix}$$

$$\times \begin{bmatrix} L & M & U \\ 0.203 & 0.419 & 0.813 \\ 0.147 & 0.302 & 0.610 \\ 0.087 & 0.178 & 0.373 \\ 0.062 & 0.101 & 0.203 \end{bmatrix}$$

$$= \begin{bmatrix} L & M & U \\ 0.180 & 0.424 & 1.021 \\ 0.091 & 0.192 & 0.362 \\ 0.098 & 0.263 & 0.705 \\ 0.054 & 0.121 & 0.320 \end{bmatrix}$$

Step 5. At this step, the local priorities of the SWOT sub-factors have been calculated by the use of fuzzy pairwise comparison matrices. The priority vectors derived from the analysis of fuzzy pairwise comparison matrices are given in Eq. (11).

$$\tilde{w}_{sub-factors(strengths)} = \begin{bmatrix} L & M & U \\ 0.283 & 0.404 & 0.577 \\ 0.042 & 0.074 & 0.123 \\ 0.233 & 0.343 & 0.501 \\ 0.074 & 0.132 & 0.220 \\ 0.032 & 0.047 & 0.084 \end{bmatrix} \quad \tilde{w}_{sub-factors(weakness)} = \begin{bmatrix} L & M & U \\ 0.094 & 0.183 & 0.347 \\ 0.170 & 0.304 & 0.530 \\ 0.130 & 0.228 & 0.402 \\ 0.038 & 0.057 & 0.094 \\ 0.130 & 0.228 & 0.402 \end{bmatrix}$$

$$\tilde{w}_{sub-factors(oppurtunities)} = \begin{bmatrix} L & M & U \\ 0.093 & 0.187 & 0.366 \\ 0.157 & 0.303 & 0.570 \\ 0.075 & 0.135 & 0.244 \\ 0.044 & 0.072 & 0.149 \\ 0.157 & 0.303 & 0.570 \end{bmatrix} \quad \tilde{w}_{sub-factors(Threats)} = \begin{bmatrix} L & M & U \\ 0.074 & 0.133 & 0.248 \\ 0.044 & 0.071 & 0.147 \\ 0.112 & 0.239 & 0.470 \\ 0.075 & 0.136 & 0.255 \\ 0.231 & 0.421 & 0.744 \end{bmatrix} \quad (11)$$

Step 6. At this step, the global priority of the SWOT sub-factors has been calculated by multiplying the priorities that have interdependence with the SWOT factors ($\tilde{w}_{factors}$, which is given in Step 4) in the local priorities of the SWOT sub-factors ($\tilde{w}_{sub-factors}$, which is given in Step 5). Calculations are presented in Table 10. The crisp values of the priorities of the SWOT factors and sub-factors are shown in Figure 5. The vector $\tilde{w}_{sub-factors(global)}$ (local priority of the sub-factors) derived by the use of global priority values in the last column of Table 10 has been presented in Eq. (12).

SWOT factors	Priority of the factors	Priority of the factors	Priority of the sub-factors	Overall priority of the sub-factors
Strengths	(0.180, 0.424, 1.021)	S_1	(0.283, 0.404, 0.577)	(0.051, 0.171, 0.589)
		S_2	(0.042, 0.074, 0.123)	(0.008, 0.031, 0.126)
		S_3	(0.233, 0.343, 0.501)	(0.042, 0.145, 0.512)
		S_4	(0.074, 0.132, 0.220)	(0.013, 0.056, 0.225)
		S_5	(0.032, 0.047, 0.084)	(0.006, 0.020, 0.086)
Weaknesses	(0.091, 0.192, 0.362)	W_1	(0.094, 0.183, 0.347)	(0.009, 0.035, 0.126)
		W_2	(0.170, 0.304, 0.530)	(0.015, 0.058, 0.192)
		W_3	(0.130, 0.228, 0.402)	(0.012, 0.044, 0.146)
		W_4	(0.038, 0.057, 0.094)	(0.003, 0.011, 0.034)
		W_5	(0.130, 0.228, 0.402)	(0.012, 0.044, 0.146)
Opportunities	(0.098, 0.263, 0.705)	O_1	(0.093, 0.187, 0.366)	(0.009, 0.049, 0.258)
		O_2	(0.157, 0.303, 0.570)	(0.015, 0.080, 0.402)
		O_3	(0.075, 0.135, 0.244)	(0.007, 0.036, 0.172)
		O_4	(0.044, 0.072, 0.149)	(0.004, 0.019, 0.105)
		O_5	(0.157, 0.303, 0.570)	(0.015, 0.080, 0.402)
Threats	(0.054, 0.121, 0.320)	T_1	(0.074, 0.133, 0.248)	(0.004, 0.016, 0.079)
		T_2	(0.044, 0.071, 0.147)	(0.002, 0.009, 0.047)
		T_3	(0.112, 0.239, 0.470)	(0.006, 0.029, 0.150)
		T_4	(0.075, 0.136, 0.255)	(0.004, 0.016, 0.082)
		T_5	(0.231, 0.421, 0.744)	(0.012, 0.052, 0.238)

Table 10. Overall priority of the SWOT sub-factors

$$\tilde{w}_{sub-factors(global)} = \begin{bmatrix} L & M & U \\ 0.051 & 0.171 & 0.589 \\ 0.008 & 0.031 & 0.126 \\ 0.042 & 0.145 & 0.512 \\ 0.013 & 0.056 & 0.225 \\ 0.006 & 0.020 & 0.086 \\ 0.009 & 0.035 & 0.126 \\ 0.015 & 0.058 & 0.192 \\ 0.012 & 0.044 & 0.146 \\ 0.003 & 0.011 & 0.034 \\ 0.012 & 0.044 & 0.146 \\ 0.009 & 0.049 & 0.258 \\ 0.015 & 0.080 & 0.402 \\ 0.007 & 0.036 & 0.172 \\ 0.004 & 0.019 & 0.105 \\ 0.015 & 0.080 & 0.402 \\ 0.004 & 0.016 & 0.079 \\ 0.002 & 0.009 & 0.047 \\ 0.006 & 0.029 & 0.150 \\ 0.004 & 0.016 & 0.082 \\ 0.012 & 0.052 & 0.238 \end{bmatrix} \quad (12)$$

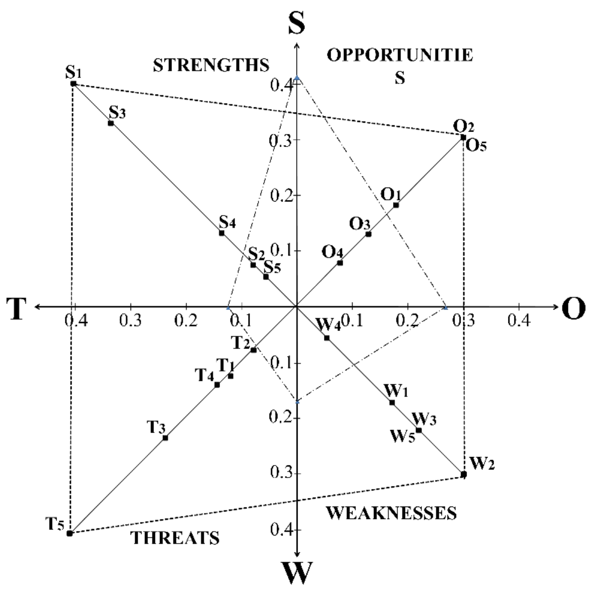

Figure 5. The graphical representation of crisp values of the priorities of SWOT factors and sub-factors based on the ANP methodology

Step 7. At this step, the importance degrees of alternative strategies have been determined with respect to the fuzzy sub-factors of the SWOT, and the relevant fuzzy matrices have been built. The finally fuzzy matrix $\widetilde{W}_4$ is obtained after analyzing these fuzzy matrices by the Microsoft Excel software package. Table 11 presents the matrix $\widetilde{W}_4 = (W_4^L, W_4^M, W_4^U)$.

Step 8. Eventually, the overall fuzzy priority of alternative strategies that reflect the interdependencies of the SWOT factors is calculated by Eq. (13).

$$\tilde{w}_{alternatives} = \begin{bmatrix} SO_1 \\ SO_2 \\ WO_1 \\ WO_2 \\ ST_1 \\ ST_2 \\ WT_1 \\ WT_2 \end{bmatrix} = \widetilde{W}_4 \times \tilde{w}_{sub-factors(global)} = \begin{bmatrix} L & M & U \\ 0.020 & 0.133 & 1.007 \\ 0.019 & 0.125 & 0.924 \\ 0.027 & 0.149 & 1.128 \\ 0.017 & 0.093 & 0.704 \\ 0.020 & 0.114 & 0.804 \\ 0.020 & 0.104 & 0.740 \\ 0.032 & 0.150 & 1.059 \\ 0.036 & 0.132 & 0.923 \end{bmatrix} \quad (13)$$

Sub-factors SWOT																				Strategies
T_5	T_4	T_3	T_2	T_1	O_5	O_4	O_3	O_2	O_1	W_5	W_4	W_3	W_2	W_1	S_5	S_4	S_3	S_2	S_1	
values- *L*																				
0.02	0.06	0.01	0.03	0.05	0.11	0.04	0.05	0.13	0.14	0.03	0.08	0.05	0.02	0.07	0.04	0.09	0.15	0.05	0.03	SO_1
0.04	0.07	0.03	0.14	0.13	0.08	0.15	0.13	0.03	0.08	0.03	0.09	0.09	0.02	0.12	0.15	0.17	0.04	0.08	0.06	SO_2
0.11	0.05	0.16	0.03	0.03	0.13	0.04	0.05	0.09	0.09	0.08	0.08	0.06	0.23	0.1	0.03	0.03	0.1	0.03	0.03	WO_1
0.09	0.03	0.08	0.09	0.1	0.1	0.1	0.11	0.06	0.06	0.05	0.04	0.05	0.06	0.02	0.03	0.03	0.04	0.02	0.04	WO_2
0.11	0.05	0.13	0.04	0.06	0.13	0.03	0.05	0.06	0.06	0.06	0.06	0.03	0.12	0.03	0.03	0.03	0.06	0.14	0.03	ST_1
0.09	0.14	0.08	0.03	0.03	0.02	0.03	0.02	0.05	0.02	0.05	0.03	0.14	0.06	0.04	0.11	0.11	0.03	0.09	0.08	ST_2
0.12	0.08	0.07	0.19	0.11	0.03	0.16	0.03	0.07	0.04	0.1	0.09	0.06	0.03	0.07	0.09	0.08	0.05	0.06	0.17	WT_1
0.11	0.05	0.08	0.11	0.07	0.03	0.06	0.03	0.07	0.08	0.11	0.06	0.04	0.03	0.06	0.11	0.06	0.06	0.05	0.14	WT_2
values - *M*																				
0.02	0.12	0.02	0.03	0.09	0.17	0.08	0.11	0.26	0.26	0.05	0.14	0.09	0.03	0.14	0.09	0.16	0.28	0.09	0.04	SO_1
0.05	0.16	0.04	0.22	0.23	0.13	0.24	0.24	0.05	0.14	0.05	0.16	0.19	0.03	0.23	0.25	0.28	0.07	0.16	0.12	SO_2
0.16	0.07	0.29	0.03	0.04	0.2	0.07	0.17	0.17	0.16	0.16	0.15	0.12	0.41	0.2	0.04	0.04	0.2	0.06	0.04	WO_1
0.13	0.05	0.12	0.14	0.18	0.16	0.17	0.21	0.09	0.1	0.11	0.07	0.09	0.11	0.03	0.04	0.04	0.06	0.03	0.08	WO_2
0.16	0.09	0.2	0.08	0.1	0.22	0.05	0.11	0.11	0.1	0.13	0.12	0.05	0.2	0.06	0.06	0.04	0.13	0.26	0.04	ST_1
0.13	0.27	0.11	0.03	0.04	0.03	0.04	0.03	0.08	0.03	0.09	0.06	0.26	0.11	0.08	0.19	0.19	0.05	0.19	0.15	ST_2
0.2	0.17	0.1	0.29	0.2	0.06	0.25	0.07	0.13	0.07	0.21	0.18	0.14	0.06	0.14	0.16	0.15	0.1	0.12	0.28	WT_1
0.16	0.08	0.12	0.18	0.13	0.05	0.1	0.06	0.12	0.13	0.22	0.13	0.08	0.06	0.11	0.18	0.11	0.11	0.11	0.24	WT_2
values - *U*																				
0.03	0.21	0.03	0.05	0.17	0.28	0.14	0.21	0.48	0.46	0.1	0.26	0.18	0.05	0.27	0.16	0.26	0.51	0.19	0.07	SO_1
0.08	0.3	0.07	0.34	0.38	0.22	0.38	0.44	0.1	0.25	0.1	0.28	0.37	0.05	0.43	0.41	0.45	0.14	0.3	0.23	SO_2
0.22	0.13	0.5	0.05	0.06	0.31	0.11	0.59	0.32	0.29	0.3	0.27	0.23	0.74	0.38	0.07	0.06	0.39	0.12	0.07	WO_1
0.2	0.09	0.18	0.23	0.31	0.25	0.28	0.39	0.16	0.18	0.21	0.14	0.18	0.19	0.07	0.06	0.06	0.11	0.06	0.16	WO_2
0.22	0.16	0.32	0.13	0.18	0.25	0.09	0.22	0.19	0.19	0.25	0.23	0.11	0.34	0.13	0.12	0.06	0.26	0.48	0.07	ST_1
0.2	0.49	0.17	0.05	0.06	0.05	0.08	0.06	0.16	0.06	0.2	0.13	0.47	0.19	0.18	0.32	0.32	0.09	0.33	0.28	ST_2
0.3	0.32	0.16	0.43	0.33	0.09	0.39	0.14	0.23	0.14	0.39	0.34	0.3	0.12	0.29	0.29	0.26	0.2	0.22	0.47	WT_1
0.23	0.13	0.18	0.29	0.22	0.08	0.15	0.12	0.21	0.23	0.39	0.25	0.15	0.11	0.21	0.31	0.2	0.22	0.21	0.4	WT_2

Table 11. Elements of the fuzzy matrix $\widetilde{W}_4$

Step 9. Finally, the triangular fuzzy weights (Eq. (13)) are converted to crisp numbers (using $d = (l + 2m + u) / 4$) and are normalized to provide a prioritization of medical equipment replacement strategies in the training hospitals of Guilan province, as presented in Eq. (14).

$$\widetilde{\mathrm{w}}_{alternatives} = \begin{bmatrix} \mathrm{SO}_1 \\ \mathrm{SO}_2 \\ \mathrm{WO}_1 \\ \mathrm{WO}_2 \\ \mathrm{ST}_1 \\ \mathrm{ST}_2 \\ \mathrm{WT}_1 \\ \mathrm{WT}_2 \end{bmatrix} = \begin{bmatrix} 0.134 \\ 0.123 \\ 0.150 \\ 0.094 \\ 0.109 \\ 0.119 \\ 0.144 \\ 0.127 \end{bmatrix} \quad (14)$$

The results of the FANP analysis reveal that the strategy WO_1 with the final weight of 0.15 is the most appropriate strategy of medical equipment replacement in the teaching hospitals of Guilan province under the status quo. Also, the second and third priorities of alternative strategies have been assigned to strategies WT_1 and SO_1 with the final weights of 0.144 and 0.134, respectively.

Discussion of Results

If MEM in hospitals and healthcare centers is organized in a sound and effective manner, it can facilitate achieving the goals of these centers. The World Health Organization (WHO) has a unique view on the organization of MEM. It believes that if there is an organized view on MEM in hospitals, it will have a significant role in reducing costs, increasing productivity, and enhancing safety (WHO, 2011). By reflecting on the lifecycle of MEM, one can understand the WHO's precise intentions for the establishment of an efficient MEM system in hospitals. But, the most important point in this cycle is the representation of the MEM system as a chain, emphasizing that full attention to all parts of this chain can help a hospital achieve effectiveness in MEM and that if a part is ignored, it would be unlikely to accomplish a serious development in the system. The representation of this system as a cycle implies the need for a continuous and dynamic MEM process so that the hospital should seek developing new designs by analyzing and evaluating all sectors at any given time. For hospitals that are at the beginning of the equipment management road, this cycle can be a roadmap of medical equipment development.

This research is the first instance of assessing medical equipment replacement in hospitals and healthcare centers using a hybrid SWOT-FANP approach. The study attempted to perform a simultaneous quantitative and qualitative assessment of the strengths, weaknesses, opportunities, and threats of medical equipment replacement in the teaching hospitals of Guilan province, Iran. Some strategies were suggested for medical equipment replacement in the studied region. The main gap about the lack of a medical equipment replacement plan in the study site is associated with the lack of information emanating from the lack of any research on medical equipment replacement in Iran. The major issues affecting medical equipment replacement in Guilan province were identified by the quantified analysis of SWOT and FANP. So, we first analyzed the external and internal environments of the teaching hospitals in Guilan province comprehensively to identify the key opportunities, threats, strengths, and weaknesses of medical equipment replacement in the studied hospitals with the aid of expert teams. Then, using a SWOT matrix, medical equipment replacement strategies were derived from the crossing of strengths with opportunities and threats and the crossing of weaknesses with opportunities and threats to identify the four categories of SO, WO, ST and WT strategies (Table 4). Then, using a fuzzy network analysis process, these strategies were prioritized with respect to the dependence of the SWOT factors. According to the results of the FANP technique, the derived scores show the sequence of the SWOT-derived strategies as Eq. (15):

$$WO_1 \rightarrow WT_1 \rightarrow SO_1 \rightarrow WT_2 \rightarrow SO_2 \rightarrow ST_2 \rightarrow ST_1 \rightarrow WO_2 \quad (15)$$

Accordingly, the strategy WO_1 with the final weight of 0.150 is the top priority among the strategies of medical equipment replacement in the teaching hospitals of Guilan province. The second priority is the strategy WT_1 with the final weight of 0.144. On the other hand, the final priority has been assigned to the strategy WO_2 with the total weight of 0.094.

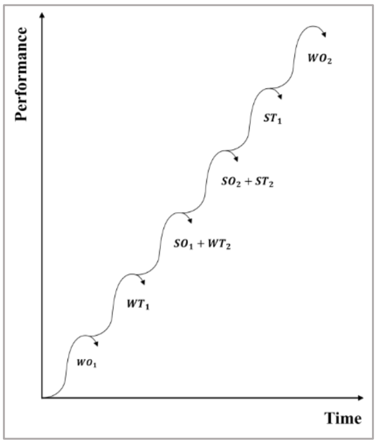

Figure 6. Chronological realization of medical equipment replacement strategies for the teaching hospitals of Guilan province

According to the benefits of the strategy ranked as the first priority, the performance of the hospitals will improve over time. Nonetheless, any strategy suffers from some constraints in its lifespan (Arsic et al., 2017), so the organization needs to adopt new strategies to keep its growing trend of performance. Therefore, the hospital management should have a plan for future actions to achieve sustainable development. The chronological realization pattern of the strategies in the present study is displayed in Figure 6. The prioritization of the defined strategies and the approximate values of the allocated weights dictate that the strategy WO_1 should be realized first. This strategy defines an expected range for improving the performance of medical equipment replacement. In addition, its realization will lay the ground for implementing other strategies. According to the model of prioritization of the defined strategies, with the adoption of the strategyWO_1, we aim to absorb credit for the replacement of medical equipment considering the governmental supports. Also, with this strategy, we want to create a positive atmosphere to support private sector investment in replacing medical equipment in the province. Once the limits are reached after the application of the strategyWO_1, the conditions are provided to implement the key strategyWT_1. Then, a specialized workgroup can be formed for the replacement of medical equipment in hospitals with the participation of both internal and external stakeholders in order to monitor the implementation of medical equipment replacement plan and to evaluate and select the best sustainable supplier of the equipment during their replacement. It should, also, be remembered that this is made possible by the adoption of the strategy WO_1 which provides the conditions and financial resources. During the implementation of the key strategyWO_1, the implementation of the strategy SO_1 should be triggered so as to take full advantage of the opportunities by relying on the strengths. Other strategies of the research are to be implemented in the same manner.

As a health tourism hub in Iran, Guilan province has significant potential in this regard. However, MEM in the hospitals of Guilan province does not go along with the formulated perspectives due to the lack of sound management activities. Despite the unstable state of MEM in the province, there are still hopes for it. In this respect, provincial and national policymakers and healthcare managers are trying to resolve current threats and weaknesses by using opportunities and strengths. Our results will help managers make optimal decisions on replacement plans, thereby assisting the optimal use of existing resources. According to the objectives of the research, i.e. identifying the key internal and external factors affecting medical equipment replacement in the teaching hospitals of Guilan province and selecting and prioritizing medical equipment replacement strategies in these hospitals in accordance with the status quo, effective implementation of the proposed strategies will contribute to achieving development goals and will ensure the movement towards an optimal condition.

6.0 Conclusions and Recommendations

Proper planning, and the adoption of this strategy, as well as other proposed strategies, can improve the process of medical equipment replacement in hospitals, and since in many cases the cost of replacing a device is much lower than depreciation costs of insisting on the use of that device, its replacement can undoubtedly reduce costs and motivate the application of new technologies in hospitals. The decision approach proposed in this study can be precious for the management of hospitals and healthcare centers and can provide them with important information on executive steps to achieve an optimal strategy of medical equipment replacement. Our results provide an interesting insight into the effectiveness of medical equipment replacement strategies, making it very close to Mkalaf (2015)'s study from the implementation perspective. The proposed model of this research and similar research (Chien et al., 2010; Bahadori et al., 2012; Khalaf et al., 2014; Miniati et al., 2014; Saleh, 2014; Horenbeek & Pintelon, 2014; Faisal & Sharawi, 2015; Jamshidi et al., 2015) can be used in the future as a planning tool for developing maintenance and replacement strategies for various medical equipment. The results showed that the ANP technique is a good way to design a comprehensive framework for MEM, which is consistent with the studies of Horenbeek and Pintelon (2014) and Bahadori et al. (2012). The ANP approach enables decision-makers to better understand complex links in a decision problem, and this enhances the validity of the decisions. This study addressed the problem of finding medical equipment replacement strategies as a multi-criteria decision-making process so as to minimize the drawbacks of efficient strategies for adoption during an indefinite planning horizon. In this respect, our work is comparable with Dehayem Nodem et al. (2011).

To avoid casualties and overhead costs in hospitals, it should be ensured that medical equipment is replaced in a systematic and planned manner. This can be achieved by a medical equipment replacement decision system. The present research developed a hybrid approach to deciding on medical equipment replacement. The approach intends to increase the self-confidence of decision-makers and owners of medical equipment and provide them with adequate supporting evidence and thereby, motivate the development of medical equipment replacement strategies under the status quo.

Planning for replacing medical equipment helps us make a balance in budgeting between different needs. According to studies in many developing countries (Than et al., 2017), the planning of medical equipment replacement has reduced normal costs significantly. Developing countries like Iran have limited funds, so it is important to ensure that healthcare technologies are invested correctly. Good management practices can create sustainable conditions for healthcare technology. This goal can be realized by planning for medical equipment replacement.

We attempted to present a valuable, important and functional decision system to plan medical equipment replacement in the studied region and during this attempt, a set of different strategies was formulated. These strategies can guide hospitals and healthcare centers in the process of decision-making for the replacement of medical equipment. The present study showed that methods such as SWOT analysis can be a useful tool for better identification of the positive and negative factors affecting medical equipment replacement in the teaching hospitals of Guilan province and other provinces of Iran. We believe that the applied hybrid approach is capable of being integrated into a decision system to replace medical equipment in all healthcare centers. Therefore, the results of the study may help the management of the Guilan University of Medical Science and other relevant organizations and institutions in MEM. Also, using our results and with the help of the presented decision system, the managers of the studied hospitals can readily and precisely rank the approaches for medical equipment replacement in the future.

Since the proposed hybrid approach can be implemented in other hospitals just after considering their internal conditions, it is suggested that the study be carried out in other provinces of Iran and the results be compared with each other. As well, the study can also be used to formulate strategies for other stages of MEM life cycle. In addition to assuming the dependencies of the main strategic factors, future research can also consider the possible dependencies between sub-factors. Future research can use newer multi-criteria decision-making methods such as WASPAS (Deveci et al., 2018), MOORA (Arabsheybani et al., 2018), COPRAS (Zheng et al., 2018), and SWARA (Zarbakhshnia et al., 2018) and compare their results with our results.

Since the process of strategic management is a dynamic and continuous process, the change in one component of the process will change some or all of the other components; so, given the current changing environment, the activities that are taken to formulate strategies has a permanent aspect and are not taken only for one single year or for every six months. Therefore, the senior managers in charge of medical equipment replacement of the studied hospitals are recommended to use our proposed diagram to synchronize the results of the study with their own strategic needs in optimal time intervals at the regional or hospital level in order to develop, update and customize the strategies adopted here and their need assessment has been performed at a provincial level. To this end, coordinators in each hospital need to consult again with the experts who participated in the present research and reconsider their views. This process is considered as complementary to the process of developing strategies for medical equipment replacement. In addition, in this process, the brainstorming technique (Al-Samarraie & Hurmuzan, 2018) can be used as a creative way to customize strategies at the hospital level. Figure 7 displays the proposed diagram of the development, update, or customization of medical equipment replacement strategies that have been formulated at the regional or hospital level using the SWOT matrix and with respect to the results of the present research. Customization of strategies ensures that strategies adopted by hospitals are aligned with their internal long-term perspectives and goals. Also, the re-examination of the internal and external environment reveals the need for changing strategies, empowers hospitals to attain their goals, and contributes to identifying potential scenarios and making possible plans for accomplishing the goals, satisfying trans-organizational perspectives, and realizing social responsibilities of hospitals.

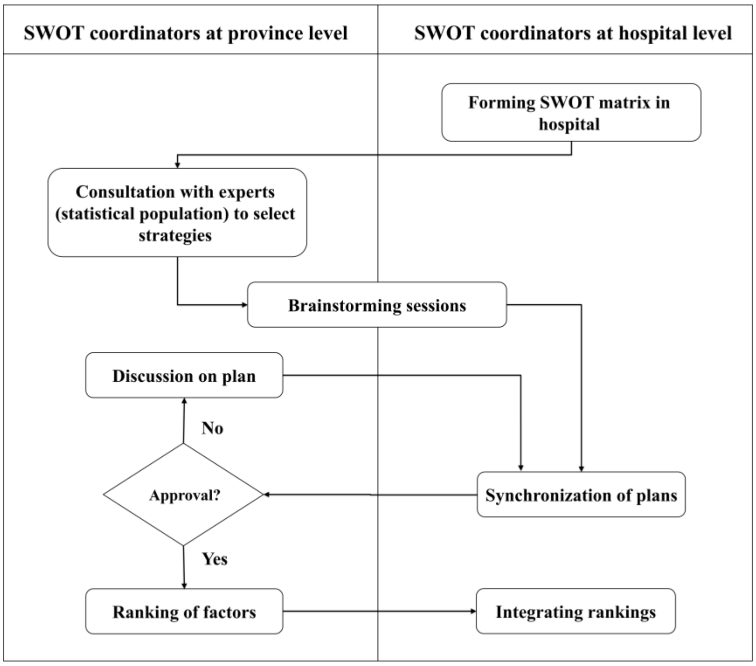

Figure 7. The proposed diagram for developing, updating and customizing replacement strategies adopted at the hospital scale with respect to the strategies of the present study at the provincial level

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