Comparative Study of AHP and Fuzzy AHP for Ranking of Medicinal Drugs

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Abstract Evaluation of healthcare policies and taking decisions with regard to complex problems require assessments at many levels and by a group of experts. This paper studies the selection criteria and their weights for the five drugs for metastatic colorectal cancer treatment. A comparative value assessment of the drugs was conducted with the analytic hierarchy process (AHP) and the fuzzy analytic hierarchy process (Fuzzy AHP) techniques of multi-criteria decision making. The ranking scores of all the alternative drugs have been examined and the implications of the vagueness in the decision making have been scrutinized for both the AHP and Fuzzy AHP.

Keywords Fuzzy set theory · Healthcare management · Multi-criteria decision making

1 Introduction

Public healthcare facilities are a determining factor in the overall development of the country [1]. Providing in-time healthcare services based on the peculiarity of admissible diseases and demographic information increases the extent of the impact. Human bias, error, and behavioural uncertainty in the decision making have led to irreversible damage in the past [2]. Implementation of an expert opinion-based

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mathematical model for taking the decision related to healthcare policies provides an optimized practical system for solving real-life problems. The rightful assessment of the impact of all the contributing factors helps is weighing the alternatives available. In the view of drug procurement, formulation of healthcare policies and inventory management at hospitals, this paper studies extent of impact of the selection criteria of drugs for metastatic colorectal cancer from five alternatives: “Bevacizumab”, “Cetuximab”, “Panitumumab”, “Aflibercept”, “Regorafenib” as taken up by Jason Chia-Hsun Hsieh et al. [3] in their study and this paper considers the same weights. The reviews of the first expert from the National Health Insurance Administration (NHIA) and the sub-criteria weights allotted by the first subject have been considered for simpler reasoning. This paper illustrates the comparison between AHP [4] and Fuzzy AHP [5] for decision making where each medicine has been studied on the basis of clinical, economic, and societal dimensions. Learning the process of hierarchical structuring through the decomposition of the problem into goals, criteria, sub-factors, and alternatives for selecting the most suitable alternative for the treatment.

As per the UN report [6], nearly half of the globe fails to receive essential medical facilities. Thus, efficient management of funds in health care, especially for the procurement of essential medicines is necessary. The effectiveness of subjective bias and varying opinion in healthcare decision making has been studied which results in the introduction of fuzziness in the problem. A comparative analysis between AHP and fuzzy AHP techniques has been performed and its implications on the selection procedure for all the alternative medicines have been examined.

2 Review of Related Work

The study conducted for selection of drugs for hypnotics by the System of Objectified Judgement Analysis(SOJA) method by Rob Janknegt et al. [7]. For the rational reasoning of the drug formularies with eight criteria for three countries that are Netherland, France, and the UK. Clinical efficacy set to be the most important criteria with 300 points. SOJA does not support decision making of individual patients as other prevailing factors like concurrent diseases are not accounted for. The scoring of the drugs was different for different countries where the cost of procurement and sleep architecture played a major role.

Evaluation of the alternatives for the treatment of healthcare waste in Istanbul was conducted. Controlled combustion, autoclaving, microwave disinfection, and landfill were considered as the alternatives for the study performed by Mehtap Dursun [8]. Fuzzy MCDM equipped authors with hierarchical classification of all the attributes. The authors used a nominal group technique for reducing the attributes of the performance. For the aggregation of the subjective opinions of all the decision-makers, this study incorporated ordered weighted averaging. The paper concluded steam sterilization as the best technique because of having minimal impact on the environment.

Selection of hospital sites in rural India using fuzzy AHP was analysed Debmallya Chatterjee et al. [9]. The authors conducted decision-making analysis for the establishment of a healthcare facility using three major and eleven sub-factors. The cost of the site along with the density of the population and availability of the transport services were taken as the most important factors. A team of twelve medical experts provided subjective inputs to the questionnaire. The study selected alternative sites for the construction in Burdwan, West Bengal, India. The defuzzified weights assigned to the sub-factors guided in the decision-making process where cost was given 46% importance, population characteristics and location were given 27% importance each. The hierarchical analysis performed by the authors can be extended for the selection of future healthcare sites in both metropolitan and rural areas.

Fuzzy AHP approach for decision making of the maintenance strategy for the medical devices was studied by Zeineb Ben Houria [10]. The strategies were designed based on time, condition, and corrective maintenance requirements. Increasing the longevity of medical devices by efficient maintenance management reduces the overall cost. The authors constructed the maintenance strategy aimed at reducing the downtime and risks associated with the device. The ranking using fuzzy AHP provided an appropriate assessment of the criticality for each device.

3 Methodology

Analytical Hierarchy Process (AHP) [11, 12] is a structured technique for organizing and analysing complex and crucial decision problems based on mathematics and psychology. This technique carries out a pairwise comparative analysis between the alternatives and some criteria to achieve a specified goal. AHP induces the selection of the most suitable alternative by ranking the alternatives with respect to each of the criteria and then finally aggregating the separate ranking results into a final result. The problem is decomposed into a hierarchical structure of goals, decision criteria, sub-factors, and alternative. Pairwise comparison is performed for all the elements of a layer starting from the bottom of the structure and a numerical value is computed for the degree of preference on a preference/ratio scale and not at 0 and 1. As shown in Fig. 1. Methodology of AHP and fuzzy AHP where the first step to identify the problem and the final goal to achieve this step also involves the selection of alternatives that are going to compete for the ranking.

In the second step, modelling of the problem is conducted into a hierarchy structure. The hierarchy is constructed while the decision-makers increase the understanding of the problem, of its context and most importantly the feelings and thoughts of other decision-makers in the panel. This step determines which level of detail is there in the ranking process. Decision-makers break down a single criterion into multiple criteria to achieve more accurate results. This breaking down surely adds up to the accuracy of the result but it also adds up to increase in the complexity of the problem and the underlying calculations in the subsequent steps. The third step is the

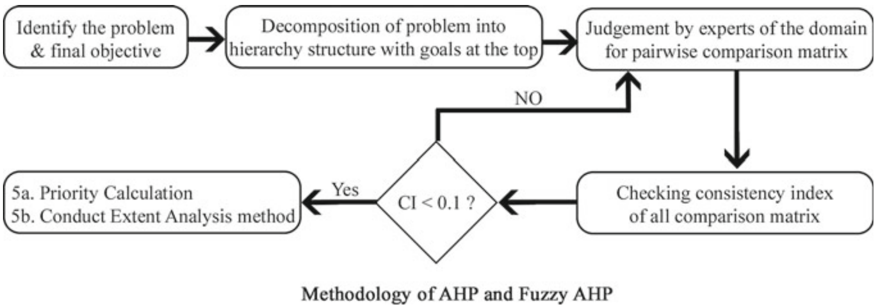

Fig. 1 Flowchart for AHP and fuzzy AHP methodology

laborious step of all. This step involves filling up the pairwise comparison matrix for each alternative for each criterion and sub-criteria, also the criteria and sub-criteria need to be compared among themselves too. The reason why this step needs so much time as the decision-makers need to debate for each pair being compared and then choose the best value. This is followed by the fourth step where the consistency ratio of each pairwise comparison matrix is analysed. If the consistency index comes out to be less than 10%, the pairwise comparison matrix can be used for further calculations, else decision-makers need to reconsider the comparison, these four steps are same for both AHP and fuzzy AHP. The difference originates from the fifth step, priority calculation is done in case of AHP and extent analysis is done in fuzzy AHP this difference then broadens because of the mathematics that follows behind further calculations.

Quantitative scrutiny of many real-life problems may not be predicted precisely by humans. Experts often make imprecise judgements leading to inconsistencies. This imperfection also reflects during the ranking procedure. To combat such a scenario, fuzzy AHP was introduced over the classical AHP model for ensuring the quantitative and qualitative factors of MCDM. Fuzzy AHP [13–15] interprets the linguistic and vague phenomenons using fuzzy set theory. Analysis of every criterion as the degree of possibility is conducted. This provides decision-makers the scope to incorporate the fuzzy nature of the problem which is very common in the real practical world. Extent analysis method results in incorporating the fuzziness of the problem and because of this, slightly different weights of the criteria are obtained due to which different scores for both AHP and fuzzy AHP are observed.

4 Simulation Results and Analysis

The comparative matrices are shown in Tables 1 and 2 for all the levels of the hierarchical structure shown in Fig. 2. AHP and then Fuzzy AHP have been deployed and the difference in the scores of both the ranking techniques has been investigated. Ranking of the cancer treatment colorectal cancer drugs are examined on the basis

Table 1 Pairwise weight assignment for criteria

Weights	Criteria								
Type of stakeholder	1.1/1.2	1.1/1.3	1.2/1.3	2.1/2.2	2.1/2.3	2.2/2.3	3.1/3.2	3.1/3.3	3.2/3.3
NHIA	3	3	2	2	3	2	1/2	1/2	2

Table 2 Criteria wise weight assignment for alternatives

Alternatives	Criteria								
	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2	3.3
Bevacizumab	2	3	2	4	5	5	4	5	4
Cetuximab	3	2	2	3	3	4	3	3	4
Panitumumab	3	2	2	4	2	3	2	2	4
Aflibercept	2	2	2	3	2	1	2	1	3
Regorafenib	1	1	3	2	3	2	2	3	4

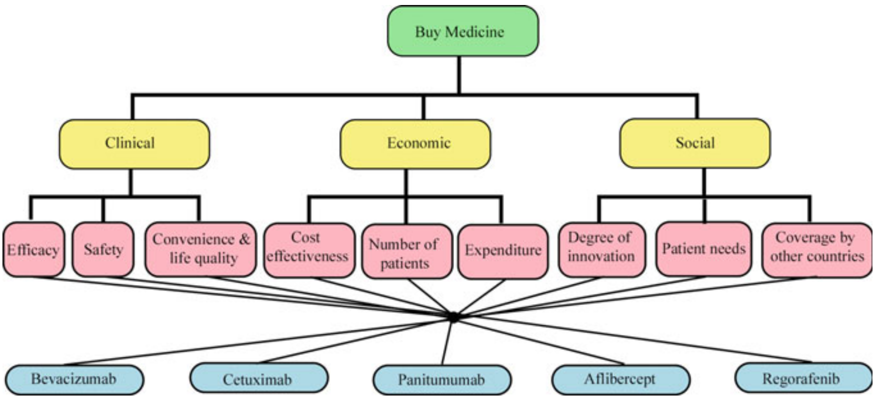

Fig. 2 Structural hierarchy for buying medicine

of three criteria that are Clinical (1), Economic (2), and Social (2) having 30%, 60%, and 10% weight respective.

The clinical criterion has further three sub-criteria namely: Efficacy (1.1), Safety (1.2) & Convenience and life quality (1.3). The economic criterion has further three sub-criteria namely: Cost-effectiveness (2.1), Number of patients (2.2) & Expenditure (2.3). The social criterion has further three sub-criteria, namely: Degree of innovation (3.1), Patient needs (3.2) & Coverage by other countries (3.3). The pairwise comparison for the comparison matrix of the criteria as set by expert is shown in Table 1 and sub-criteria weight have been represented in Table 2. AHP and fuzzy AHP provide ranks to the alternatives namely: “Bevacizumab”, “Cetuximab”, “Panitumumab”, “Aflibercept”, “Regorafenib”.

For sample illustration, the clinical comparative matrix weights have been shown in Tables 3 and 4. The result was in favour of "Bevacizumab" which had an AHP score of 3.800363 and a defuzzified fuzzy AHP score of 3.857013. This was the spotlight of our experiment as both the scores were different although the same data was fed to both the models shown in Table 5.

As we derive from Table 5, the scores of each alternative/drug is different for the case of AHP and fuzzy AHP. This is because of the underlying mathematics of the fuzzy numbers which is different from simple crisp numbers. Tables 3 and 4 showcase that the inverse of 2 is 1/2 in the case for fuzzy inverse 1 2 3 is 1/3,1/2,1/1. Fuzzy numbers are associated with fuzzy AHP which is determined by a triangular membership function with a width of 2. The consistency ratio of the comparison matrix is checked and that summed to be 0.05155921 for clinical sub-criteria, 0.008848762 for economic sub-criteria and 0.05155921 for social sub-criteria comparison. That is considered well enough to go as the AHP model works fine up to a consistency ratio of 10%. After that, we need to reconsider the matrix to produce trustable results.

So, in fuzzy numbers, decision-makers gets a bit of flexibility in determining comparison matrix which is similar to real-world problems. An interesting feature of fuzzy AHP is that the criteria which are very less important as compared to other criteria are given weights of 0 that is very logical. This is not possible in the case of normal AHP technique due to pairwise comparison using crisp numbers.

Table 3 Comparison matrix for sub-criteria of clinical criteria (CRISP NUMBERS)

Subcriteria versus sub-criteria	Efficacy	Safety	Convenience and life quality
Efficacy	1	3	3
Safety	1/3	1	2
Convenience and life quality	1/3	1/2	1

Table 4 Comparison matrix for sub-criteria of clinical criteria (FUZZIFIED)

Subcriteria versus sub-criteria	Efficacy	Safety	Convenience and life quality
Efficacy	(1; 1; 1)	(2; 3; 4)	(2; 3; 4)
Safety	(1/4; 1/3; 1/2)	(1; 1; 1)	(1; 2; 3)
Convenience and life quality	(1/4; 1/3; 1/2)	(1/3; 1/2; 1)	1; 1; 1)

Table 5 Scores of all the alternatives

Alternatives	AHP SCORE	Fuzzy AHP score
Bevacizumab	3.800363	3.857013
Cetuximab	3.007226	3.045464
Panitumumab	2.985845	2.993812
Aflibercept	2.287877	2.291056
Regorafenib	2.083912	2.121714

Running the AHP model in R studio using a standard package of fuzzy AHP gave the advantage of comparing a large number of alternatives without filling large pairwise comparison matrix for each criterion for all five alternatives. As we observe Table 5, depicting the final scores of alternatives exhibits a difference in scores of alternative 1 and alternative 2. In the case of fuzzy AHP is 3.800363-3.007226 = 0.793137 and for the case of AHP, it is 3.857013-3.045464 = 0.811549. So we see that according to fuzzy AHP, alternative 1 is much better than alternative 2.

Although the difference is small, in a strong competitive environment, it can solve major conflicts as in practical world certain cases may arise where due to the fuzzy nature of the environment, some of the ranking orders get changed. This can result in drastic losses to organizations that do not consider fuzziness which should always be taken care of.

5 Conclusion

In this study, we have ranked five medicines for the treatment of colorectal cancer using a famous multi-criteria decision-making technique known as AHP and fuzzy AHP. The results clearly sketch out "Bevacizumab" with the highest AHP score of 3.800363 and a defuzzified Fuzzy AHP score of 3.857013. Different scores for AHP and Fuzzy AHP are observed for the same data, and the relative difference between the scores also vary in both famous techniques. Although this is due to slightly different mathematics in the case of fuzzy AHP because of involvement of fuzzy numbers which increases complexity in computation but gives trustable results in fuzzy environment. The study shows that the fuzzy AHP incorporates the fuzziness in comparing two alternatives. Therefore, in a competitive environment, the ranking may be changed due to the involvement of fuzzy numbers and give different results from that of Normal AHP.

So we may conclude that AHP is optimal when we compare alternatives using crisp numbers but despite the computation complexity, in real life, it is better to incorporate the uncertainties and fuzzy nature of comparison using fuzzy AHP in those cases. So it all depends on the decision-maker whether to use AHP or fuzzy AHP as a decision-making technique based on the dominance of the fuzzy nature of the environment.

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