An Assessment of Chemotherapy Drugs with Incomplete Information using the Analytic Hierarchy Process and Choquet Integral

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Abstract

Background and Objectives: Obviously, cancer is one of the most prevalent deadly health problems that have seriously impacted societies. Although experts have been able to treat many patients, choosing the right therapeutic strategy and right medication for patients is still a challenge. Chemotherapy is one of the most common therapeutic strategies for cancer, which could be combined with radiotherapy or surgery. Since various chemotherapy drugs are available, depending on different criteria, oncologists may prescribe one chemotherapy medication or another.

Methods: Analytic Hierarchy Process (AHP) as one of the most effective decision-making methods, is applied in this paper. AHP relies on pairwise comparison matrix (PCM) that offers preferential relationships between alternatives. However, due to inaccurate and uncertain information, the revised geometric mean method (RGM) is applied in PCM. Also, considering the importance of interactions between criteria in the investigated issue, Choquet integral was employed for ranking alternatives.

Findings: Antimetabolites with weight 0.473868421 is the most preferred alternative. Plant alkaloids with weight 0.232740616, Alkylating agents with weight 0.17723893 and Anti-Tumor Antibiotics with weight 0.11819451, are alternative priorities for a chemotherapy drug, respectively.

Conclusion: In this paper, 10 questionnaires have been completed by oncologists in the hospital. According to the received results, Antimetabolites are the most preferred alternative among other chemotherapy drugs.

Keywords: Multi-criteria decision making, Analytic hierarchy process, Revised geometric mean method, Choquet fuzzy integral, Chemotherapy.

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1- Introduction

Cells, as the basic units that make up the body, are constantly replaced by division. Cancer, is the name given to the disease, when this orderly process interferes with genetic changes. In such a case, the cell is reproduced uncontrollably at an abnormal rate and spread into surrounding tissues (Tsoucalas et al, 2018). In recent decades, cancer has had a high mortality rate around the world (Fitzmaurice et al, 2017).

Nowadays, Chemotherapy is one of the most common therapeutic strategies for cancer, which could also be combined with radiotherapy or surgery (Salimi et al, 2008). Chemotherapy drugs prevent cancer cells from growing or destroy the dividing cells. Most often, chemotherapy is given as an infusion into the patient’s vein; it is noteworthy that this therapeutic approach might have many side effects, because it may also damage the healthy cells (e.g., cells in the heart, kidneys, bladder, lungs, and nervous system). Since various chemotherapy drugs are available, oncologists prescribe chemotherapy medications, based on different criteria. Experts tend to give chemotherapy drugs at a suitable level to treat cancer while keeping side effects at a minimum. Additionally, they avoid to prescribe multiple drugs with similar side effects (Tsoucalas et al, 2018). Accordingly, determining the proper chemotherapy drug requires the use of new techniques in the field of multi-criteria decision-making. AHP method proposed by Saaty (1980), helps decision-makers (DMs) to encounter complicated criteria (Ishizaka and Labib, 2011), and reach to the best possible decision.

Up to now, there are many hospital studies that have used the AHP method. For instance, (Sahin and Ocak, 2018) used the AHP to select the best place to build a hospital. (Koksalims et al, 2018) helped surgeons to choose the most effective type of surgery for the testicles. Also, (Nazari and Fallah, 2018) used a fuzzy AHP method to review different methods of diseases diagnosis and evaluated the conditions of heart patients. Furthermore, other studies using MCDM techniques that have helped to improve the decision-making process including mobile health-care products (Liu et al, 2018), blood supply chain (Ghatreh Samani and Hosseini Motlagh, 2018), and blood network design (Ghatreh Samani et al, 2018).

Specially, MCDM techniques are used for planning cancer treatments and prescribing drug doses. For example, using MCDM techniques, side effects of the treatment process were decreased and oncologists could make effective decisions about the treatment of prostate cancer (Malekpoor et al, 2018). In AHP, a multi-criteria decision problem is considered as a hierarchical structure of criteria and alternatives. It is necessary for DMs, to ensure coherence in their adjudication in the light of consistency. This is an essential part of the reliable use of AHP (Karanik et al, 2016).

But, DMs express their preferences with qualitative relations, so some times adjudication will be inconsistent. Especially, when the decision is made in a group, qualitative relations may not properly represent the features (Zhang, 2016). Consequently, sometimes DMs prefer to miss some comparisons (Benítez et al, 2011), which leads to incomplete pairwise comparisons.

So far, many authors have commented on incomplete AHP. Harker (1987) and Uden (2002) are pioneers, in considering missing data in pairwise comparison matrices (PCM). They introduced the PCM matrix with missing entry, and then to fill the missed entries, they used the scaling and averaging methods on the non-missing matrix entries. Afterward, there are few mathematical methods available to eliminate incomplete, unclear information and uncertainties, which is one of the shortcomings of AHP. An approach to this issue is a theory which is introduced by Dempster (1967) and developed by Shafer (1976) called Dempster –Shafer (DS) evidence theory; which is a powerful mathematical tool for dealing with uncertainties. Accordingly, incomplete AHP based on DS theory and by using evidence, has been developed by Huang (2014). As another approach, it should be mentioned to the using the random set theory application on the incomplete pairwise comparison (Utkin, 2009). Also, the back propagation algorithm in a multi-layer perceptron (MLP) neural network is used to access the missed and unknown elements (Hu and Tsai, 2006).

Likewise, the traditional decision-making methods, consider the criteria to be independent of each other, but this assumption has limitations to represent the best alternative (Grabisch, 1996). In the real world, most criteria have interactions with each other (Choquet, 1953). So, it is necessary to consider the interaction between criteria. Choquet integral proposed by Choquet (1953), has been used in many studies, and it is applied to assessment problems as an actual application (Bottero et al, 2018). Numerous hospital studies used the interaction of criteria in their decisions. Perçin (2018) examined the quality of healthcare websites and consider the interaction characteristics between decision criteria by Choquet integral. Medical laboratory services using MCDM methods and fuzzy set theory are evaluated by (Shekarian et al, 2017). Also (Singh and Pradher, 2017) used fuzzy techniques to improve the quality of hospital services and prioritize health care features. In addition, these techniques have been used to select the health care suppliers and improve the logistics process (Goh et al, 2018).

Furthermore, Lee (2010) employed fuzzy density (i.e. fuzzy integral) for evaluating the energy of office buildings. Also fuzzy integral is utilized to aggregate the gaps (Liou et al, 2014) in the supplier evaluation problem. (Tan et al, 2015) used the Choquet integral to calculate the dominance degree of each alternative, over the other alternatives. (Demirel et al, 2017) selected suitable sites for underground natural gas storage by using Choquet integral in data envelopment analysis (DEA), in which negative or positive interactions between inputs (or outputs) of DMUs is considerable. To apply such interactions, Choquet integral is impressed on DEA (Xia and Chen, 2017). Choquet integral employed based on Shannon's entropy, for ensembling neural classifiers as an aggregation methodology (Pacheco and Krohling, 2018). Meanwhile, the fuzzy integral and fuzzy measure are used for computing the relative importance of different attributes (Vyas et al, 2018).

According to the literature, the research gap is concluded as follows:

The lack of information is an important issue that occurs in many cases such as hospitals; whilst, there is no evidence of incomplete information. On the other hand, considering the interaction between criteria in the healthcare system is not much attended. So, a study with these issues in mind in the healthcare system would be necessary. Furthermore, as an academic viewpoint, no combination of incomplete AHP and Choquet integral was found in previous studies of healthcare industries.

So, taking into account the above descriptions, the proposed method would be a new combination of the revised geometric mean method (RGM) which is used in incomplete AHP, with Choquet integral in healthcare issues.

In addition, the applicability and efficiency of the proposed method in the healthcare system can be considered as follows:

Due to the importance of the relationship between selected criteria, experts usually prescribe appropriate chemotherapy drugs after examining factors such as disease-related area, the patient’s weight, the patient's age, rate of progression of the disease, etc. These factors or criteria are interdependent and experts should choose the best treatment given the interplay between them. This interaction and dependency are replied by Choquet integral method. Also incomplete AHP by taking incomplete data on criteria and alternatives into a hierarchical structure with complete data, transforms a complex issue into a hierarchical structure and it's application on scrutinizing the issue of chemotherapy, would be a very efficient and flexible way to choose the best alternatives.

Based on above descriptions, the main steps of this study, would be as follows:

Step1. Get the incomplete pairwise comparisons matrix (IPCM) of the criteria and alternatives.

Step2. Compute the weights of criteria and relative weights of the alternatives by using the eigenvector method.

Step3. Rank the alternatives through the Choquet fuzzy integral, based on obtained decision matrix.

The partitioning of this study is shown as follows: Section 2 presents several preliminaries. In section 3 the process of developing new method is introduced. In Section 4, the case study is introduced and implemented. Section 5 is dedicated to conclusion and summarization, as the last part of this study.

2- Basic Concepts

2.1. AHP

Analytic hierarchy process (AHP) is one of the most comprehensive MADM models, in which comparisons are made in pairs between alternatives and also between criteria. This method was introduced and developed by Saaty (1980) for the first time. One of the advantages of this method includes the possibility of formulating the problem as a multi-level hierarchical structure which shows the main problem in a simpler way and with the high compliance of this method with the minds of individuals.

AHP algorithm

After collecting all the necessary pairwise comparisons at all levels, the following steps are used to perform AHP calculations: Firstly, create a pairwise comparison matrix (PCMs). Secondly, determine the importance of each pair to the scale using a range of 1 to 9 such as a numerical rating which is indicated in Table 1. Thirdly, extract the relative weights using eigenvector method. Then, measure the consistency index (CI) to verify PCMs and finally, calculate the global weights and rank the alternatives accordingly.

Definition 1

Assuming $(A_1,\ldots,A_i,\ldots,A_n)$ are n decision elements, then the nominal scale can be used to make PCM as follows:

$A_{n\times n}$ =$[a_{ij}]$, which satisfies:

$$\boldsymbol{a_{ij}}=1/\boldsymbol{a_{ji}} \tag{1}$$

Definition 2

If there is a square matrix A (i.e. PCM matrix), eigenvalue can be calculated by the eigenvector to determine the consistency index (CI) as follows:

Calculate the matrix determination of $(A-\lambda I)$ and set it to zero and then calculate the values of λ. Then, the largest λ, which is called λ_{max}, and the related eigenvector is used to calculate the values of w_i (weights) as shown in below.

$$(\boldsymbol{A}-\boldsymbol{\lambda_{max}} \times \boldsymbol{I})\,\boldsymbol{W} = \boldsymbol{0} \qquad \lambda_{max} \geq n \tag{2}$$

Definition 3

If λ_{max} implies the maximum amount of eigenvalues in a matrix $A_{n\times n}$, CI is presented as:

$$\boldsymbol{C.I.}=\frac{\boldsymbol{\lambda_{max}}-\boldsymbol{n}}{\boldsymbol{n}-\boldsymbol{1}} \tag{3}$$

Definition 4

The consistency rate is calculated as follows:

$$\boldsymbol{C.R.}=\frac{\boldsymbol{C.I.}}{\boldsymbol{R.I.}} \tag{4}$$

Where *R.I.* is the random index which is determined based on Table 2. If the consistency rate is less than 0.1, the matrix is consistent and the weights are reliable. Otherwise, decision-makers with the highest inconsistencies should repeat the pairwise comparisons (Saaty, 1980).

Table 1. Numerical rating in AHP (Saaty, 1980)

Value	Comparison of a_i with a_j	Definition
1	Equally Preferred	Two elements have the same value
3	Moderately Preferred	Element a_i is somewhat more important than a_j
5	Strongly Preferred	Element a_i is more important than a_j.
7	Very strongly Preferred	Element a_i has a much higher priority than a_j.

9	Extremely Preferred	Element a_i is more important than a_j and not comparable
2,4,6,8	Intermediate values in judgments	For example, 8 indicate the importance of more than 7 and lower than 9 for a_i.

Table 2. Random consistency index ($R.I.$) (Saaty, 1980)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49

2.2 Revised geometric mean method

The RGM method, presented by Harker (1987), extends the Saaty's (1980) approach to non-negative semi-reciprocal matrices to use in incomplete preferences. Harker's method does not reconstruct the matrix but adapts it by less information.

2.3 Fuzzy measure and Choquet integral

Fuzzy measurement theory method is one of the most efficacious cumulative methods to consider monotonous features that can substitute additive feature with a monotony feature (Sugeno, 1974).

Let X be a set of criteria and P(X) be the power sets of X, then g can be defined as non-additive fuzzy density on X with the following features (Sugeno, 1974).

i. $g(\emptyset) = 0$, $g(X) = 1$ boundary

ii. $If\ A , B \in P(X) and\ B \subseteq A , then\ g(B) \leq g(A)$ monotonicity

3- Research Methodology

In this section, a hybrid approach is introduced to decide on incomplete pairwise comparisons matrix in AHP method with the criteria interdependencies. The proposed method is a combination of the revised geometric mean method in response to data incompleteness of pairwise comparison matrices in AHP and Choquet fuzzy integral in response to interrelation between criteria and to the best of the authors' knowledge, there is no study related to combination of these two topics with each other in such a way developed in this research.

The research method is applied-survey research, in terms of data collection with a field study. Due to the results are used in the hospital decision-making issues, this research has a practical purpose. The required data are collected by experts. It should be noted that the experts have the necessary information about the criteria and alternatives and provide the perfect results. Also, articles and databases are used to collect information on theoretical foundations and research literature.

The steps and the flowchart of the proposed method are presented as follow:

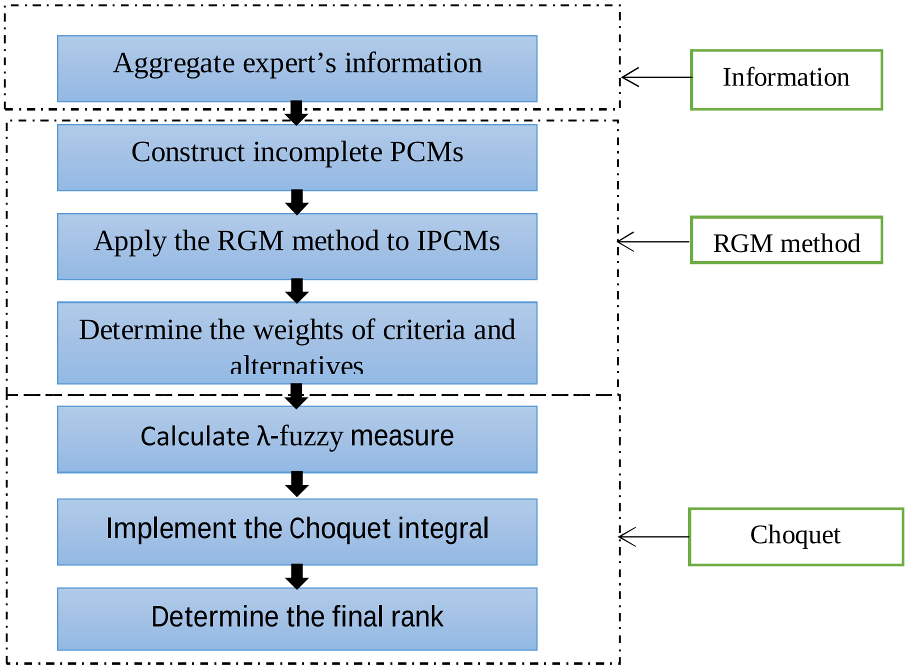

Figure 1. The flowchart of the proposed method

1. Construct the complete pairwise comparison matrices from incomplete PCMs:

In this step, the incomplete pairwise comparison matrices (IPCM) is completed by utilizing the revised geometric mean (RGM) method which is also known as the Harker's method using equation (5). In fact, with RGM method, an auxiliary matrix D is constructed as follows:

$$D_{ij}=\begin{cases} 1+m_i, & \forall i=j \\ a_{ij}, & \forall i \neq j \text{ and } a_{ij} \text{ not missing} \\ 0 & a_{ij} \text{ is missing} \end{cases} \tag{5}$$

In which m_i is the number of unknown elements at row i. After using this method, the vector of priority can be estimated using the eigenvector method on matrix D.

2. Calculate the CR

In order to be sure about the consistency; CR is calculated for each pairwise comparison matrices by using equations 3 and 4.

3. Compute the weights

The weights are extracted by using the eigenvector method as shown in equation (2).

In fact: $(D-\lambda_{max} \times I)\,W = 0$ $\quad\lambda_{max} \geq n$

4. Calculate λ-fuzzy measure

Consider $X = \{x_1, x_2, \ldots, x_n\}$; if the fuzzy density g on power set P(X) involves the following equation, the λ-fuzzy density, which presents the interaction between each set A_1 and A_2, can be measured regarding this equation (Sugeno, 1974).

$$g(A_1 \cup A_2) = g(A_1) + g(A_2) + \lambda g(A_1) g(A_2) \quad (6)$$

where $\lambda \epsilon [-1, \infty]$ for $\forall A_1, A_2 \in P(x)$ and $A_1 \cap A_2 = \emptyset$.
By generalizing equation (6) into all elements of X, we will have:

$$g(x) = \begin{cases} -\frac{1}{\lambda}[\prod_{i=1}^{n}(1 + \lambda g(x_i)) - 1], & if\ \lambda \neq 0 \\ \sum_{i=1}^{n} g(x_i), & if\ \lambda = 1 \end{cases} \quad (7)$$

Then, the λ which can be implied by boundary condition $g(x) = 1$ is obtained by the following equation:

$$\lambda + 1 = \prod_{i=1}^{n}(1 + \lambda g(x_i)) \quad (8)$$

5. Rank the alternatives through the Choquet fuzzy integral:

Concerning properties of fuzzy measure $f(x)$ which is a monotone function, as follows:

$$f(x_1) \geq f(x_2) \ldots . \geq f(x_n) \geq 0 \quad (9)$$

The Choquet integral can be defined with the following functions.

Let describe f be a measurable function on the set $X = (x_1, x_2, ..., x_n)$ and g be a fuzzy measure on X (Modave and Grabisch, 1998); then:

$$\int f dg = \sum_{i=1}^{n} f(x_i)[g(A_i)\text{-}g(A_i\text{-}1)] \quad (10)$$

And also the following equation is considerable (Tzeng, 2011).

$$\begin{aligned} \int f dg &= f(x_n).g(H_n)+[f(x_{n-1}) - f(x_n)].g(H_{n-1}) + \ldots + [f(x_1)\text{-}f(x_2)].g(H_1) \\ &= f(x_n).[g(H_n)\text{-}g(H_{n-1})] + f(x_{n-1}).[g(H_{n-1})\text{-}g(H_{n-2})] + \ldots + f(x_1).g(H_1) \end{aligned} \quad (11)$$

Where $H_1 = \{x_1\}$, $H_2 = \{x_1, x_2\}, \ldots, H_n = \{x_1, x_2, \ldots, x_n\}$

In fact, considering equation (9) in criteria priorities at each alternative, the rank of that alternative can be calculated using equation (11).

4- Numerical Results

In this section, the numerical results are described according to the model which is developed in previous section. In this study, 4 alternatives with 10 criteria have been proposed to decide on the type of drugs in which the criteria and alternatives are introduced in Tables 3 and 4, respectively. The criteria and alternatives are cited from “medical news today”[1] which is within the top 10

[1]- www.medicalnewstoday.com

most popular health websites of worldwide by providing concise and accurate information, targeted at both physicians and the general public.

At first, 10 questionnaires in relation with 10 pairwise comparison matrices of alternatives and one questionnaire for one pairwise matrix for criteria have been designed and used to select the appropriate drug. The questionnaires are completed by 10 oncologists in a hospital in Tehran.

It should be noted that these criteria are interactive. In other words, the criteria cannot be considered independently to select appropriate drugs for chemotherapy. For example, "the rate of progression of the disease” and “other diseases of the patient" has interactions with each other. So, their interaction is considered by applying Choquet integral.

Table 3. Criteria for the selection of a suitable method

Code	Description
Sco1	The disease-related area
Sco2	The rate of progression of the disease
Sco3	The patient's age
Sco4	The Patient’s weight
Sco5	The other diseases of the patient
Sco6	The time between treatments
Sco7	The treatment by injection
Sco8	The treatment by medicine
Sco9	Choosing a drug with fewer side effects
Sco10	A blood test before starting treatment

Alternatives should be further described. There are different medications and different ways to get chemotherapy. Four main categories are:

i. Antimetabolites: This approach simulates the proteins that the cell needs for survival. The cells do not benefit from their absorption and therefore die from starvation. Purine antagonists, pyrimidine antagonists, and folate antagonists are examples of such proteins.
ii. Alkylating agents: This approach, without medication, affects the patient's body and also affect the cellular DNA. Meanwhile, they kill many cells at each life cycle.
iii. Plant alkaloids: In this approach, the batches of cells prevent the increase in cell divisions. Actinomycesin D, Doxorubicin and Mitomycin are drug samples of this approach.
iv. Anti-tumor antibiotics: In this approach, some substances are attached to the DNA and prevent the synthesis of Arany; thus, the other cell cannot be divided. Doxorubicin, mitochondrion, and Bleomycin are the drug samples of this approach.

Alternatives considered in this paper, are shown in Table 4.

Table 4. Candidate alternatives for the selection criteria

Code	Description
A1	Antimetabolites
A2	Plant alkaloids
A3	Alkylating agents
A4	Anti-tumor antibiotics

As well, the hierarchical structure of this study is also shown in Figure 2.

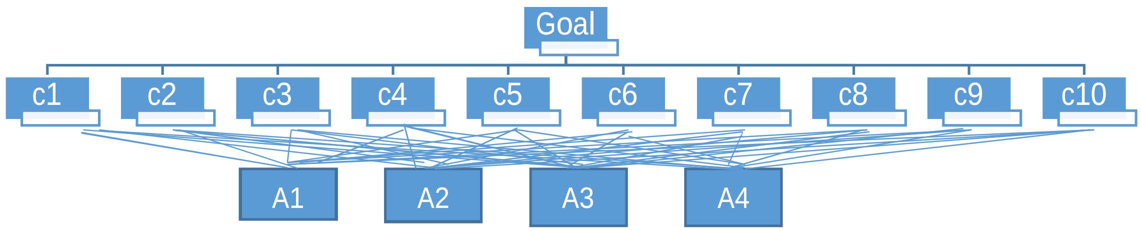

Figure 2. The hierarchical structure

As known, The PCMs offer preferential relationships between alternatives. In this study, after filling out the questionnaires by chemotherapy experts, 4 incomplete PCMs are obtained with unfilled comparisons. The IPCM of criteria and alternatives are shown in Table 5 and Table 6 respectively. Also, the other filled PCMs are presented in Appendix 1.
According to Table 5, in comparison between criteria, eight missing elements above the original diameter of the matrix, are exist. This is because of too much number of comparisons in this matrix which consequently, the decision maker prefers to miss some comparisons.

Table 5. Incomplete pairwise comparison matrix for criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1	*	1.6800	1.68	*	1.8600	1.6800	1.5700	2.0590	1.1890
C2	*	1	8.2066	6.4352	*	1.4142	4.2420	8.7388	6.3440	3.2350
C3	0.5952	0.1218	1	3.93	1.3160	*	1.6817	1.1892	1.4142	1.4142
C4	0.5952	0.1553	0.2544	1	1.3160	*	*	*	1.8612	2.2790
C5	*	*	0.7598	0.7598	1	3.3097	2.2130	*	7.9370	1.3165
C6	0.5376	0.7071	*	*	0.3021	1	3.6628	2.9129	1.5650	1.4140
C7	0.5952	0.23573	0.5946	*	0.4518	0.2730	1	1.1890	1	1.4142
C8	0.6369	0.11443	0.8409	*	*	0.3433	0.8410	1	2.4130	1.5650
C9	0.4856	0.15762	0.7071	0.5372	0.1259	0.6389	1	0.4144 1	1	1.1890
C10	0.8410	0.30911	0.7071	0.4387	0.7595	0.7072	0.7071	0.6389 7	0.8410	1

Also, at each pairwise comparisons of alternatives with respect to the criteria C2, C9, C10, one missing element is exist as shown in Table 6. In these matrices, unlike all other comparisons, there was strong disagreement on one of comparisons and so, this comparison is considered to be missed.

Table 6. iPCMs for alternatives

C2	A1	A2	A3	A4	C9	A1	A2	A3	A4	C10	A1	A2	A3	A4
A1	1	6	3	*	A1	1	1.75	1.5	2.25	A1	1	*	5.50	1.75
A2	0.16	1	1.75	1.25	A2	0.57	1	*	2.75	A2	*	1	2.25	4
A3	0.33	0.86	1	2	A3	0.66	*	1	3	A3	0.18	0.44	1	1.25
A4	*	0.8	0.5	1	A4	0.44	0.36	0.33	1	A4	0.57	0.25	0.8	1

The RGM method has been applied using equation (5). To implement this method, zero is set instead of each missing elements and for each zero element, one unit is added to the original diameter as shown in Tables 7 and 8. Then, eigenvalues and eigenvectors are extracted for these new matrices. The application of this method reduces the inconsistency in the PCMs.

Table 7. The RGM method for IPCM of criteria

	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**
C1	3	0	1.6800	1.6800	0	1.8600	1.6800	1.5700	2.0590	1.1890
C2	0	3	8.2066	6.4352	0	1.4142	4.2420	8.7388	6.3440	3.2350
C3	0.5952	0.1218	2	3.93	1.3160	0	1.6817	1.1892	1.4142	1.4142
C4	0.5952	0.1553	0.2544	4	1.3160	0	0	0	1.8612	2.2790
C5	0	0	0.7598	0.7598	4	3.3097	2.2130	0	7.9370	1.3165
C6	0.5376	0.7071	0	0	0.3021	3	3.6628	2.9129	1.5650	1.4140
C7	0.5952	0.2357	0.5946	0	0.4518	0.2730	2	1.1890	1	1.4142
C8	0.6369	0.1144	0.8409	0	0	0.3433	0.8410	3	2.4130	1.5650
C9	0.4856	0.1576	0.7071	0.5372	0.1259	0.6389	1	0.4144	1	1.1890
C10	0.8410	0.3091	0.7071	0.4387	0.7595	0.7072	0.7071	0.6389	0.8410	1

Table 8.The RGM method for iPCMs of alternatives

C2	**A1**	**A2**	**A3**	**A4**	**C9**	**A1**	**A2**	**A3**	**A4**	**C10**	**A1**	**A2**	**A3**	**A4**
A1	2	6	3	0	A1	1	1.75	1.5	2.25	A1	2	0	5.50	1.75
A2	0.16	1	1.75	1.25	A2	0.57	2	0	2.75	A2	0	2	2.25	4
A3	0.33	0.87	1	2	A3	0.66	0	2	3	A3	0.18	0.44	1	1.25
A4	0	0.80	0.5	2	A4	0.44	0.36	0.33	1	A4	0.57	0.25	0.8	1

To check the consistency, λ_{max} and CR are calculated according to equation (4) for all comparisons and also for hierarchy as shown in Table 9. According to the pairwise comparison method in AHP, it should be noted that these comparisons are not statistical questionnaires and their validity and reliability are measured using consistency rate taking into account whether or not this rate is below 0.1. This rate is examined and the validation is approved for all comparison matrices and also for hierarchy successfully.

Table 9. λ_{max} and consistency rate (CR)

pairwise comparison matrix	**Complete**	**Incomplete**	**RGM's method**	λ_{max}	**CR**
PCMs for criteria		✓	✓	11.077	0.078
PCMs for an alternative to c1	✓			4.140	0.051
PCMs for an alternative to c2		✓	✓	4.247	0.091
PCMs for an alternative to c3	✓			4.223	0.080
PCMs for an alternative to c4	✓			4.103	0.038
PCMs for an alternative to c5	✓			4.188	0.061
PCMs for an alternative to c6	✓			4.115	0.042
PCMs for an alternative to c7	✓			4.260	0.096
PCMs for an alternative to c8	✓			4.038	0.014
PCMs for an alternative to c9		✓	✓	4.067	0.022
PCMs for an alternative to c10		✓	✓	4.224	0.082
Total hierarchical process					0.075

In fact, the validity of this study is measured in two stages. First, the consistency rate of each pairwise comparison matrix is calculated. As can be seen, all values of CR are less than 0.1. next, the consistency rate for the entire hierarchical is calculated. As can be seen in the latest row of Table 9, this rate is also less than 0.1. So the numerical results are reliable and acceptable.

Table 10. Relative weights of alternatives

W	0.09608	0.30684	0.09235	0.07172	0.13548	0.097963	0.05008	0.0537	0.04125	0.05449
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
A1	0.669215	0.6067046	0.425201	0.3351630	0.326318	0.324164	0.435561	0.441813	0.3604504	0.399099
A2	0.134747	0.1491548	0.274607	0.3130968	0.287538	0.319408	0.228467	0.280008	0.2486840	0.352237
A3	0.107803	0.1562941	0.158799	0.2190560	0.218480	0.224246	0.206046	0.159504	0.2788406	0.120677
A4	0.088233	0.0878466	0.141387	0.1326848	0.167662	0.132182	0.129923	0.118671	0.1120233	0.127985

Table 10 illustrates the decision matrix which is resulted from AHP method. Each column represents the relative weights of alternatives in response to one of the criteria. The first row also represents the relative weights of the criteria in response to the goal.

At the next step, Choquet integral and fuzzy measure are used on this Table to consider the interaction relationships among criteria. As shown in Table 11, the relative weights of criteria are used for calculating the λ measure.

Table 11. The fuzzy measure obtained from the eigenvector method

$g(x_1)$	$g(x_2)$	$g(x_3)$	$g(x_4)$	$g(x_5)$	$g(x_6)$	$g(x_7)$	$g(x_8)$	$g(x_9)$	$g(x_{10})$
0.09608	0.30684	0.09235	0.07172	0.13548	0.097963	0.05008	0.0537	0.04125	0.05449

Based on equation (8), λ is calculated to be 0.40111 and then concerning equation (9), the fuzzy density of 10 criteria for alternative A1 is calculated as shown in Table 12. Also, the fuzzy density of other alternatives can be similarly calculated which are presented in Appendix 2.

Table 12.The fuzzy measures of A1

Fuzzy sets	value
$g(\{x_1, x_2\})$	0.41475674
$g(\{x_1,x_2,x_8\})$	0.45735813
$g(\{x_1,x_2,x_8,x_7\})$	0.50683832
$g(\{x_1,x_2,x_8,x_7,x_3\})$	0.59916051
$g(\{x_1,x_2,x_8,x_7,x_3,x_{10}\})$	0.65364343
$g(\{x_1,x_2,x_8,x_7,x_3,x_{10},x_9\})$	0.69489018
$g(\{x_1,x_2,x_8,x_7,x_3,x_{10},x_9,x_4\})$	0.76660939
$g(\{x_1,x_2,x_8,x_7,x_3,x_{10},x_9,x_4, x_5\})$	0.90208910
$g(\{x_1,x_2,x_8,x_7,x_3,x_{10},x_9,x_4, x_5,x_6\})$	1

Table 12, shows the monotonicity property as well. For example, $g(\{x_1, x_2, x_8\}) > g(\{x_1, x_2\})$ and so on. Now, according to the calculated fuzzy measure of each criterion and using equations (10) and (11), the value of each alternative is obtained, as shown in Table 13.

Table 13. The final results of the Choquet method

Code	**Description**	**value**
A1	Antimetabolites	0.47386842
A2	Plant alkaloids	0.23274061
A3	Alkylating agents	0.17723893
A4	Anti-tumor antibiotics	0.11819451

The results show that Antimetabolites with weight 0.473868421 is the most preferred alternative and Plant alkaloids with weight 0.232740616, Alkylating agents with weight 0.17723893 and Anti-tumor antibiotics with weight 0.11819451, respectively are the other priority alternatives for chemotherapy drugs.

According to the results and given the interaction between criteria, Antimetabolites that inhibit the metabolism of a microorganism, were identified as the most effective drug that oncologists can use them to treat cancers such as leukemia, by soliding tumors which are neoplastic disorders. Also, due to the toxicity of alkaloids to overcome pathogens and their predators (Matsuura and Fett-Neto, 2015), they can be used as defense compounds in plant alkaloids.

As managerial insights, it can be mentioned that generally, qualitative issues such as the lack of time for experts to respond, lack of sufficient awareness, inconsistency in the opinions of the experts, etc.; are some inevitable issues that can lead to incomplete information. Meanwhile, the the existence of interaction between the decision making factors in human being aspects such as healthcare, is also inevitable. The proposed model solution can help experts to make better decisions about the different issues in healthcare considering these inevitable issues and factors.

Applying the presented method can provide appropriate orientation for achieving important decision goals. It also helps experts (i.e. physicians) to manage their decisions efficiently and select the best drug, the best treatment, the best surgical procedure and so on, for their patients.

Table 14. Ranking of alternatives in different value of λ

λ	A1	A2	A3	A4
600	3.39545998	0.25905377	0.19026105	0.18387805
800	4.36997532	0.26783069	0.19460466	0.20578721
1000	5.34449065	0.27660761	0.19894827	0.22769637

Eventually, to verify the proficiency of the developed method, ranking is done in the large values of λ. Based on Table 14, results show that in λ=600, the ranking of the alternatives has not changed yet and is similar to the initial results; but in λ=800 and λ=1000, the third and fourth alternative ranks have changed and Alkylating agents with weight 0.19894827 is the last priority. However, Antimetabolite in any values of λ, is the first alternative. Since the changes are happened only in the very large values of λ, we can conclude that the results imply the validity and robustness of the proposed method.

5- Conclusion

Overall, the purpose of chemotherapy is to treat with various medications. In its particular sense today, it has been used for the treatment of various tumors (Cancer). Hence, using anticancer drugs or chemotherapy is one of the best ways to treat these tumors. Chemotherapy is very effective way in the treatment of tumors, and this effect is increasing with the discovery of new anti-tumor drugs. There are several medications to get chemotherapy depending on different criteria for choosing them. Decision-making methods can be used for choosing the best one.

In this study, AHP is used for this issue. According to this method, 11 questionnaires have been completed by oncologists in the hospital. Unfortunately, the results of some questionnaires were incomplete or unacceptable due to the expert's lack of sufficient information about the subject, lack of time to complete the questionnaires and disagreements on the preference criteria. To deal with this problem, the revised geometric mean method is used. Also, concerning the importance of considering the interactions between the criteria, the Choquet integral was employed for ranking the alternatives.

Finally, according to the present methods, Antimetabolites with the weight of 0.473868421 is the most preferred alternative and Plant alkaloids, Alkylating agents, Anti-tumor antibiotics have respectively the next priorities.

For further research, the method can be developed for incomplete information and Choquet integral with different preferences. Also, complete uncertainty can be considered by linguistic values and using fuzzy AHP. Besides, to consider the other aspects of interaction in criteria, ANP can be used instead of AHP in future studies. Additionally, other uncertainty approaches such as DS theory, grey relational analysis method, and rough set theory can be used instead of fuzzy set theory.

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I. Appendix 1

Complete PCMs of alternatives for C1, C3, C4, C5, C6, C7, C8

C1	**A1**	**A2**	**A3**	**A4**
A1	1	6.25	5.75	7.25
A2	0.16	1	1.50	1.75
A3	0.17	0.66	1	1.50
A4	0.13	0.57	1	1

C3	**A1**	**A2**	**A3**	**A4**
A1	1	2.5	2.75	1.75
A2	0.40	1	2.50	2.25
A3	0.36	0.40	1	1.75
A4	0.57	0.44	0.57	1

C4	**A1**	**A2**	**A3**	**A4**
A1	1	1.25	1.75	2
A2	0.80	1	2	2
A3	0.57	0.50	1	2.5
A4	0.50	0.50	0.40	1

C5	**A1**	**A2**	**A3**	**A4**
A1	1	1.75	1.50	1.25
A2	0.57	1	2	1.75
A3	0.66	0.5	1	2
A4	0.80	0.57	0.50	1

C6	**A1**	**A2**	**A3**	**A4**
A1	1	1.25	1.25	2.50
A2	0.80	1	2.25	1.75
A3	0.80	0.44	1	2.25
A4	0.40	0.57	0.44	1

C7	**A1**	**A2**	**A3**	**A4**
A1	1	3.5	1.75	2
A2	0.28	1	1.75	2
A3	0.57	0.57	1	2.25
A4	0.50	0.50	0.44	1

C8	**A1**	**A2**	**A3**	**A4**
A1	1	1.50	2.25	4.75
A2	0.66	1	2	2
A3	0.44	0.50	1	1.25
A4	0.21	0.50	0.80	1

II. Appendix 2

Fuzzy measures of A2

Fuzzy sets	**value**
$g(\{x_{10}, x_6\})$	0.1545897
$g(\{x_{10},x_6,x_4\})$	0.2243215
$g(\{x_{10},x_6,x_4,x_5\})$	0.3596684
$g(\{x_{10},x_6,x_4,x_5,x_8\})$	0.4134403
$g(\{x_{10},x_6,x_4,x_5,x_8,x_3\})$	0.5057904
$g(\{x_{10},x_6,x_4,x_5,x_8,x_3,x_9\})$	0.5470372
$g(\{x_{10},x_6,x_4,x_5,x_8,x_3,x_9,x_7\})$	0.5971216
$g(\{x_{10},x_6,x_4,x_5,x_8,x_3,x_9,x_7,x_9\})$	0.9039641
$g(\{x_1,x_2,x_8,x_7,x_3,x_{10},x_9,x_4,x_5,x_1\})$	1

Fuzzy measures of A3

Fuzzy sets	**value**
$g(\{x_9, x_6\})$	0.1408307
$g(\{x_9,x_6,x_4\})$	0.2110454
$g(\{x_9,x_6,x_4,x_5\})$	0.3464246
$g(\{x_9,x_6,x_4,x_5,x_7\})$	0.3964941
$g(\{x_9,x_6,x_4,x_5,x_7,x_8\})$	0.4502849
$g(\{x_9,x_6,x_4,x_5,x_7,x_8,x_3\})$	0.5426360
$g(\{x_9,x_6,x_4,x_5,x_7,x_8,x_3,x_2\})$	0.8494784

$g(\{x_9,x_6,x_4,x_5,x_7,x_8,x_3,x_2,x_{10}\})$	0.9039641
$g(\{x_9,x_6,x_4,x_5,x_7,x_8,x_3,x_2,x_{10},x_1\})$	1

Fuzzy measures of A4

Fuzzy sets	**value**
$g(\{x_5 ,x_3\})$	0.2328494
$g(\{x_5,x_3,x_4\})$	0.2999099
$g(\{x_5,x_3,x_4,x_6\})$	0.3975483
$g(\{x_5,x_3,x_4,x_6,x_7\})$	0.4475993
$g(\{x_5,x_3,x_4,x_6,x_7,x_{10}\})$	0.5020833
$g(\{x_5,x_3,x_4,x_6,x_7,x_{10},x_8\})$	0.5558748
$g(\{x_5,x_3,x_4,x_6,x_7,x_{10},x_8,x_9\})$	0.5971216
$g(\{x_5,x_3,x_4,x_6,x_7,x_{10},x_8,x_9,x_1\})$	0.6932096
$g(\{x_5,x_3,x_4,x_6,x_7,x_{10},x_8,x_9,x_1, x_2\})$	1