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# A Fuzzy Dematel Method To Evaluate The Most Common Diseases In Internal Medicine

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**Abstract** Most patients have more than one disease, and these diseases are able to affect one another. In modern medicine, the etiology and pathophysiology of diseases are well known in detail. However, inter-disease relationships are still mysterious. Physicians' knowledge and experience have great importance in such a multi-criteria case. Because medical doctors in internal medicine clinics deal with large numbers of patients with multiple diseases, they have quite a complex approach in treating illness. In this context, exposing the cause-and-effect relationships among diseases frequently seen in internal medicine will contribute to physicians' ability to blend profound theoretical knowledge with experiential results. Therefore, this study presents a fuzzy DEMATEL (Decision-Making Trial-and-Evaluation Laboratory) method to assess the most common diseases in internal medicine outpatient clinics. The DEMATEL method allows one to identify and analyze significant diseases in internal medicine by considering the cause-and-effect relationship diagram. Likewise, fuzzy sets in DEMATEL overcome the uncertainty in making decisions about disease relationships and internal medicine experts' judgments. When investigating the results, we have found dyspepsia, hyperlipidemia, and anemia to be crucial in terms of causes. When evaluating the effects, the most notable diseases are understood to be renal failure, malignancy, and hepatitis. The results indicate that in the presented study, we could successfully apply these methods to reveal the cause–effect of diseases. The results of this study will contribute to understanding the complex multi-criteria relationship among internal diseases using internists' opinions.

**Keywords** Fuzzy DEMATEL · Internal medicine · Disease · Diagnose

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## 1 Introduction

Internal medicine can be defined as a field of medical expertise for adult-patient comprehensive care focused on diagnosing and preventing the diseases that affect internal organs and systems. Modern medicine has much information available on the etiology, diagnosis, and treatment of internal disease in internal medicine [1, 2]. The complexity of the many mechanisms of diseases makes understanding the interrelationships of these diseases difficult and prevents the physician from making accurate diagnoses. Integrating certain engineering techniques with medical knowledge would be beneficial by considering the positive reflections of a multidisciplinary study on such complex situations. From a medical point of view, engineering techniques have a well-defined syntax and methodologies where clearly defined meanings of the represented profundity of medical knowledge may emerge. In modern medicine, specialist knowledge more often predominates over textbook data. Many studies and classifications have been made on knowledge-based systems (KBS) over the medicine-related information in the literature [3, 4]; fuzzy logic [5] currently has an important place here. Also data and information in the medical field depend on the experience of specialists who have a proportional integration of personal and field knowledge detecting, diagnosing, interpreting and treating diseases [6]. Both the genetic algorithm technique [7–9] and fuzzy logic [10–13] have been implemented in many different fields of medicine, and their popularity has been increasing. In addition, fuzzy logic has been applied successfully in various fields apart from medicine [14–19]. Methods such as fuzzy clustering, fuzzy classification, fuzzy modeling, and fuzzy identification are often used in medical applications [6]. The fuzzy c-regression model (FCRM), possibility c-means (PCM) clustering algorithm [20], fuzzy c-means (FCM) clustering algorithm [21] and entropy-based fuzzy clustering (EFC) algorithm [22] have been successfully used in medicine recently. The current study successfully implements the fuzzy DEMATEL technique over the most common diseases of internal medicine. In the literature, Shieh et al. [23] used the DEMATEL method to identify the important success parameters for hospital service quality. Liu et al. [24] worked on healthcare waste (HCW) management, which is a public health and environmental issue. Liu et al. proposed a new, hybrid, multi-criteria decision-making (MCDM) model by integrating the 2-tuple DEMATEL technique and the fuzzy MULTIMOORA method to select HCW treatment alternatives. Ghadami et al. [25] carried out a study using the fuzzy DEMATEL technique to rank and weigh hospitals' accreditation categories, subcategories, and standards. These standards can improve a hospital's strengths and weaknesses. As a result of their study, hospitals can make positive changes by taking effective measures and paying special attention to the main body of management. Mahmoudi et al. [26] carried out a study identifying the 10 factors affecting heart failure self-care. The aim of their study was to reduce the complexity of the heart failure self-care process and optimize it as a critical success factor. As a result, the authors used the fuzzy DEMATEL method to identify the factors in heart failure self-care for uncertain environments. Nilashi et al. [27] aimed to identify the factors affecting the development of medical tourism in Malaysia using the DEMATEL and fuzzy TOPSIS methods. Zhu et al. [28] applied a hybrid MCDM model that integrated the 2-tuple DEMATEL technique and the fuzzy VIKOR method into the problem of selective admission control. They did this because evaluating each patient's acceptance priority is based on uncertain dimensions or uncertain data among the evaluation dimensions and criteria. Jiang et al. [29] carried out a study that proposed the Z-DEMATEL method for identifying key performance parameters in healthcare management. Their results showed cases/errors, accidents/adverse events, hospital infections, nursing technology transition rates, and duration of stay to be key parameters for the given application. Jeng and Tzeng [30] used fuzzy DEMATEL to examine whether social patterns influence the intended behavior medical doctors use in presenting a new Clinical Decision Support System. Reyna and Lloyd [31] carried out a study on assessments and outcomes for nine hypothetical patients at three levels of cardiac risk. The results had good agreement with the fuzzy-trace theory, and specialists also accomplished better results when considering less information. Fathi-Torbaghan and Meyer [32] studied a fuzzy logic-based system for medical diagnostic decision support on acute abdominal pain. Abbod et al. [33] performed a detailed analysis on using fuzzy logic and its possible future effects in many medical sciences. With records from the hospital information system, one of the most successful practices of fuzzy logic has been computer-assisted diagnosis (CADIAG). The literature, shows the latest version of the CADIAG-2 system to have had applications in the areas of gastroenterology, rheumatology, and hepatology over the past few decades [34, 35].

The DEMATEL method deals with inter-criteria relationships in terms of the cause-and-effect relationship and provides an assessment of the relationship strengths among criteria. This method visualizes the complex relationships among criteria on a graph and allows decision-makers to evaluate inter-criteria relations more easily. This method divides criteria into two parts: the cause group and the effect group. The DEMATEL method can prioritize factors in terms of relationship type and significance of their impact on each other. Thus, high-priority criteria with more impact on other factors are called cause criteria, while those that are more affected and thought to have low priority are called effect criteria. This can determine the criteria that have greater impact on solving the problem and, less so, reduce the number of criteria in the problem. Although the fuzzy DEMATEL technique has been properly applied over many other fields and subjects, its successful application in internal diseases is rare. Therefore, aside from prior studies this study will remedy the gap in the internal medicine literature and reflect the opinions of internists in terms of understanding the relationships most common internal diseases have. Complex internal diseases are strongly known to have crucial relationships among these factors. Therefore, this study will contribute to medical doctors' theoretical approach using their experiential knowledge.

This study has been prepared as follows: the research methodologies are given in "Research Methodologies" section. "An Illustrative Example of Fuzzy DEMATEL" section examines internal diseases and how the study has been applied through the necessary subsections. "Result and Discussion" section gives the results and discussion.

## 2 Research Methodologies

This paper uses fuzzy sets and the DEMATEL method to assess the most common and significant diseases in internal medicine outpatient clinics. The following section explains fuzzy sets and DEMATEL methodologies.

## 2.1 Fuzzy Set Concept

In 1965, Lotfi A. Zadeh developed a method for evaluating decision-making with using fuzzy logic in situations involving multiple parameters and their related uncertainties ambiguities. When examining decision-making problems in any real-life process, many decisions seem to originate from precisely unknown constraints and uncertain events [36]. Translating linguistic terms into fuzzy numbers is considered more logical than blending the ideas, opinions or decisions that emerge from the expertise of individuals/groups, as mathematics gives more objective answers.

Therefore, the problems of group decision-making require generating fuzzy numbers to be put into effect. A triangular fuzzy number can be stated as a triplet $\tilde{A} = (l, m, u)$ where *l, m,* and *u* denote the lower, medium, and upper numbers of the crisp fuzzy set and real numbers $(x \leq y \leq z)$, respectively. The membership function of a triangular fuzzy number is shown below.

$$\mu_{\tilde{A}} = \begin{cases} 0. & x < l \\ (x-l)/(m-l), & l \leq x \leq m \\ (u-x)/(u-m), & m \leq x \leq u \\ 0 & x \geq u \end{cases} \quad (1)$$

Within this scope, Fig. 1 illustrates a triangular fuzzy number. The ersatz relation among the lingual terms of experts (internists in our case) and triangular fuzzy numbers is identified according to Table 1. Consequently, fuzzy ratings and their membership function is depicted in Fig. 2.

Assuming two triangular fuzzy numbers $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$, the mathematical estimating of the two triangular fuzzy numbers can be described as below:

The inset process among the triangular fuzzy numbers

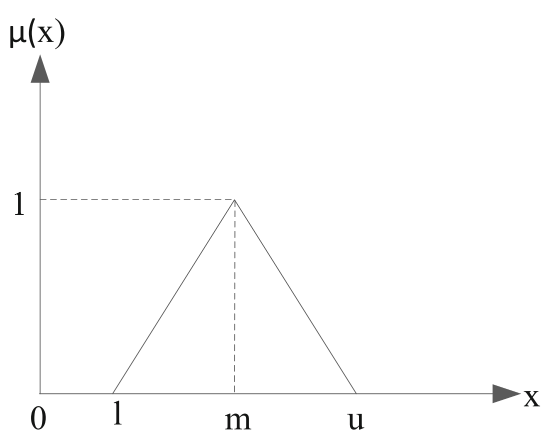


**Fig. 1** Triangular fuzzy number

**Table 1** Relevance of linguistic terms and fuzzy numbers

| Linguistic terms | Triangular fuzzy numbers |
|---|---|
| No influence (No) | (0, 0, 0.25) |
| Very low influence (VL) | (0, 0.25, 0.5) |
| Low influence (L) | (0.25, 0.5, 0.75) |
| High influence (H) | (0.5, 0.75, 1) |
| Very high influence (VH) | (0.75, 1, 1) |

$$\tilde{A}_1 + \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

The removal operation among the triangular fuzzy numbers

$$\tilde{A}_1 - \tilde{A}_2 = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \quad (3)$$

The multiplication operation among the triangular fuzzy numbers

$$\tilde{A}_1 \; x \; \tilde{A}_{21} = (l_1 x l_2, m_1 x m_2, u_1 x u_2) \quad (4)$$

The arithmetical operation for the triangular fuzzy numbers

$$kx \, \tilde{A}_1 \; = \; (kxl_1, kxm_1, kxu_1), (k > 0) \quad (5)$$

$$\frac{\tilde{A}_1}{k} = \left(\frac{l_1}{k}, \frac{m_1}{k}, \frac{u_1}{k}\right), (k > 0). \quad (6)$$

$$D = \frac{1}{\max_{1 \leq i \leq n} \sum_{j=1}^{n} a_{ij}} \quad (7)$$

$$T = D(1 - D)^{-1} \quad (8)$$

$$r_i = \sum_{1 \leq j \leq n} t_{ij} \quad (9)$$

$$c_j = \sum_{1 \leq i \leq n} t_{ij} \quad (10)$$

## 2.2 Integration of Applied Techniques

In this section, fuzzy sets and DEMATEL methods are integrated to accomplish precision assessment. Application order of methods of the fuzzy DEMATEL approach is given in Fig. 3. The fundamental steps of the integrated method is described as below [37–41].

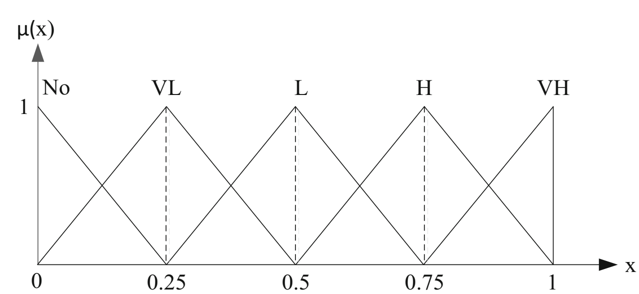


**Fig. 2** Fuzzy ratings and their membership function

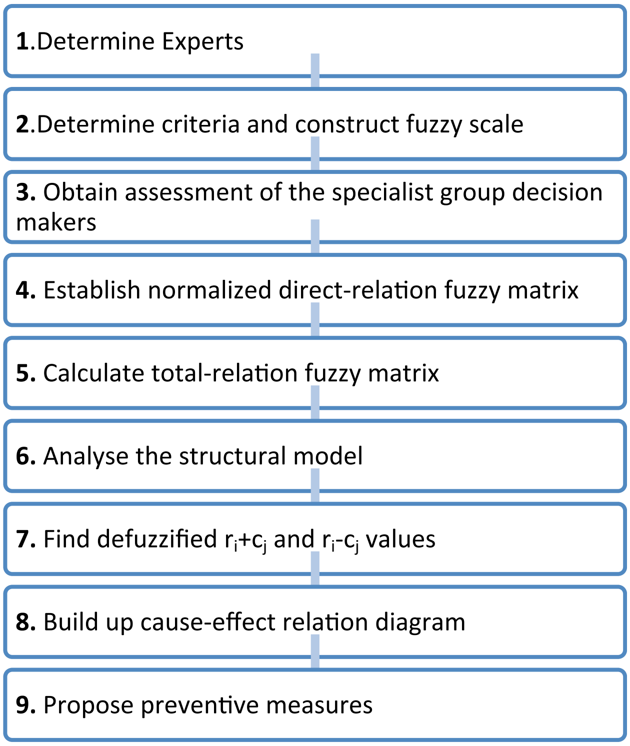


**Fig. 3** Application order of the Fuzzy DEMATEL method

Step 1 Determine experts: Here, it should be consulted to the experts who have profound knowledge and enough experience about the problem to acquire coherent assessments.
Step 2 Determine criteria and construct fuzzy scale: In this section, important components (in our case, diseases) are determined to be analyzed and assessed appropriately. So, linguistic variable is utilized with five scales (No, VL, L, H, and VH) due to the verbal terms and fuzzy numbers. Thenceforth, corresponding triangular fuzzy members are given.
Step 3 Obtain assessment of the specialist group decision-makers: Double wise comparison is acquired in terms of linguistics variables. Moreover, the fuzzy evaluations are converted into defuzzified and aggregated as a crisp value. Eventually, initial direct-relation fuzzy matrix ($\tilde{E}$) of group decision-makers is created.

$$\tilde{E} = \begin{bmatrix} 0 & \cdots & \tilde{E}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{E}_{n1} & \cdots & 0 \end{bmatrix} \tag{11}$$

$$\tilde{e}_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right) \tag{12}$$

Step 4 Set-up normalized direct-relation fuzzy matrix: With the help of existing the initial direct-relation matrix, normalized direct-relation fuzzy matrix is built. Due to accomplish that, first of all it is considered $\tilde{\beta}_i$ and $\gamma$ as triangular fuzzy numbers. Next calculations are carried out, respectively.

$$\tilde{\beta}_i = \sum \tilde{e}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right) \tag{13}$$

$$\gamma = \max\left(\sum_{j=1}^{n} u_{ij}\right) \tag{14}$$

Moreover, the linear scale transformation is implemented to convert the components into corresponding scales. The normalized direct-relation fuzzy matrix ($\tilde{F}$) of group decision-makers is depicted as below.

$$\tilde{F} = \begin{bmatrix} \tilde{\tilde{F}}_{11} & \ldots & \tilde{F}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{F}_{n1} & \ldots & \tilde{F}_{nn} \end{bmatrix} \tag{15}$$

where $\tilde{f}_{ij} = \frac{\tilde{e}_{ij}}{\gamma} = \left(\frac{\tilde{e}_{ij}}{\gamma}, \frac{\tilde{e}_{ij}}{\gamma}, \frac{\tilde{e}_{ij}}{\gamma}\right)$
Step 5 Determine total-relation fuzzy matrix: After getting established normalized direct-relation fuzzy matrix, a total-relation fuzzy matrix is created by making sure that $\lim_{\omega \to \infty} F^{\omega} = 0$.
After, the crisp case of the total-relation fuzzy matrix is identified as below.

$$\tilde{T} = \lim_{\omega \to \infty}\left(\tilde{F} + \tilde{F}^2 + \ldots + \tilde{F}^{\omega}\right) \tag{16}$$

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \ldots & \tilde{t}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{t}_{n1} & \ldots & \tilde{t}_{nn} \end{bmatrix} \tag{17}$$

where $\tilde{t}_{ij=} = \left(l_{ij}^{''}, m_{ij}^{''}, u_{ij}^{''}\right)$

$$\text{Matrix}\left[l_{ij}^{''}\right] = F_l x(I - F_l)^{-1} \tag{18}$$

$$\text{Matrix}\left[m_{ij}^{''}\right] = F_m x(I - F_m)^{-1} \tag{19}$$

$$\text{Matrix}\left[u_{ij}^{''}\right] = F_u x(I - F_u)^{-1} \tag{20}$$

Step 6 Analyze the structural model: After calculating matrix $\tilde{T}$, $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$ are calculated. In the formula, $\tilde{r}_i$ and $\tilde{c}_j$ denote the sum of the rows and columns of matrix $\tilde{T}$. While $\tilde{r}_i + \tilde{c}_j$ shows the importance of factor $i$, $\tilde{r}_i - \tilde{c}_j$ shows the net effect of factor $i$.
Step 7 Defuzzify $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$: Thereafter, $\tilde{r}_i + \tilde{c}_j +$ and $\tilde{r}_i - \tilde{c}_j$ are defuzzified using COA (center of area) defuzzification technique which is presented by Ross [15] for determining BNP (best non-fuzzy performance) value. For a convex fuzzy number $\tilde{\delta}$, a real number $z^*$ corresponding to its center of area can be calculated with below formula [42].

$$z^* = \frac{\int \mu_{\tilde{\delta}}(z) z dz}{\int \mu_{\tilde{\delta}}(z) dz} \quad (21)$$

The BNP value of a fuzzy number $\tilde{G} = \left(l_{ij}, m_{ij}, u_{ij}\right)$ can be determined with following formula.

$$BNP_{ij} = \frac{u_{ij} - l_{ij} + m_{ij} - l_{ij}}{3} + l_{ij} \quad (22)$$

Step 8-Build-up cause–effect relation diagram: Last, the cause and effect relation diagram is illustrated by representing the dataset of $r_i + c_j$ and $r_i - c_j$. The calculation can be done with the step 6 approach.

## 3 An Illustrative Example of Fuzzy DEMATEL

This part includes the fuzzy DEMATEL method that has been applied to assess diseases in internal medicine outpatient clinics. The majority of patients who come to a hospital due to an internal disease have one or more of the diseases mentioned in Table 2. Investigating the cause-and-effect relationship among these diseases is very helpful and can guide doctors in their treatment. This study includes 15 frequently seen diseases. The encountered diseases are not limited to these; while the number of diseases can be increased, the diseases listed here are known to be found in a predominant percentage of internal medicine patients. In addition, how the network of relationships among diseases will reach satisfaction can be seen by approaching this issue through different methods. When looking at weights, evaluations may vary due to slightly different cases and the medical doctor's level of experience. However, these unique situations do not change the general approach.

**Table 2** Most common diseases in the internal medicine outpatient clinic

| | |
|---|---|
| C1 | Diabetes mellitus |
| C2 | Parathyroid function disorder |
| C3 | Anemia |
| C4 | Hypertension |
| C5 | Thyroid function disorder |
| C6 | Coagulation disorders |
| C7 | Hyperlipidemia |
| C8 | Gout disease |
| C9 | Hepatitis |
| C10 | Rheumatoid arthritis |
| C11 | Heart failure |
| C12 | Dyspepsia |
| C13 | Renal failure |
| C14 | Chronic obstructive pulmonary disease |
| C15 | Malignancy |

### 3.1 Determining of Internal Medicine Experts and Problem Description

Three internal medicine specialists were involved the Fuzzy DEMATEL method's primary implementation. These doctors have worked as internal medicine specialists for 20, 10, and 5 years, respectively. These specialists were first asked to determine the 15 most frequent diagnoses for patients who apply to the internal medicine outpatient clinics. The specialists' determined 15 diseases identified as 'C' in Table 2. These 15 diseases have been randomly assigned.

The specialists were asked about the relationship each of these 15 diseases has with the other 14 in terms of cause and effect. The specialists filled verbal scales without knowing the other's answers. They were asked to select the options of 'No influence,' 'Very low influence,' 'Low influence,' 'High influence,' and 'Very high influence' for each relationship on the scale, as indicated in Table 1. As the internists were asked about the relationships each of the 15 diseases has with the other 14 diseases, a total of 210 relationships have been found.

### 3.2 Practical Application of the Proposed Fuzzy Set Concept and the DEMATEL Method

Significant and common diseases related to internal medicine are given in Table 2. The internists were asked what they understand about the relationships among diseases. Then, the internists evaluate the relationship among diseases using the fuzzy verbal scale. Accordingly, Table 3 indicates the initial direct-fuzzy matrix. Next, the established initial direct-fuzzy matrix and normalized direct-relation fuzzy matrix were created using Eqs. 13, 14, 15 respectively. Table 4 demonstrates the normalized initial direct-relation fuzzy matrix. Furthermore, the total-relation fuzzy matrix has been able to be determined with the help of Eqs. 16, 17, 19, 20. Moreover, Table 5 shows the total-relation fuzzy matrix. Table 6 indicates the defuzzified threshold values of the T-matrix, and Table 7 illustrates the fuzzy values for $\tilde{r}i$, $\tilde{c}j$, $\tilde{r}i + \tilde{c}j$, $\tilde{r}i - \tilde{c}j$. Finally in light of the above and with the help of Eqs. 21 and 22, Table 8 provides the crisp results.

(C1 Diabetes mellitus, C2 Parathyroid function disorder, C3 Anemia, C4 Hypertension, C5 Thyroid function disorder, C6 Coagulation disorders, C7 Hyperlipidemia, C8 Gout disease, C9 Hepatitis, C10 Rheumatoid arthritis, C11 Heart failure, C12 Dyspepsia, C13 Renal failure, C14 Chronic obstructive pulmonary disease, C15 Malignancy).

**Table 3** The initial direct-relation fuzzy matrix

| | C1 | C2 | C3 | C4 | … | C12 | C13 | C14 | C15 |
|---|---|---|---|---|---|---|---|---|---|
| C1 | (0, 0, 0.25) | (0, 0.17, 0.42) | (0.08, 0.17, 0.42) | (0.67, 0.92, 1) | … | (0.08, 0.33, 0.58) | (0.67, 0.92, 1) | (0.25, 0.50, 0.75) | (0.08, 0.17, 0.42) |
| C2 | (0, 0.25, 0.50) | (0, 0, 0.25) | (0, 1, 1) | (0.17, 0.42, 0.67) | … | (0.17 0.42, 0.67) | (0.67, 0.92, 1) | (0, 0.08, 0.33) | (0.25, 0.50, 0.75) |
| C3 | (0.17, 0.33, 0.58) | (0,33 0.50, 0.67) | (0, 0.17, 0.42) | (0, 0.08, 0.33) | … | (0.17, 0.42, 0.67) | (0.75, 1, 1) | (0, 0.08, 0.33) | (0.75, 1, 1) |
| C4 | (0.75, 1, 1) | (0.50, 0.75, 0.92) | (0.17, 0.33, 0.58) | (0, 0, 0.25) | … | (0, 0.017 0.42) | (0.67, 0.92, 1) | (0.33, 0.58, 0.83) | (0.17, 0.25, 0.50) |
| … | … | … | … | … | … | … | … | … | … |
| C12 | (0.25, 0.50, 0.75) | (0.25, 0.50, 0.75) | (0.08, 0.17, 0.42) | (0.08, 0.17, 0.42) | … | (0, 0, 0.25) | (0.33, 0.58, 0.83) | (0.17, 0.42, 0.67) | (0.50, 0.75, 0.92) |
| C13 | (0.67, 0.92, 1) | (0.42, 0.67, 0.83) | (0.50, 0.75, 1) | (0.75, 1,1) | … | (0.08, 0.25, 0.50) | (0, 0, 0.25) | (0.25, 0.50, 0.75) | (0.17, 0.42, 0.67) |
| C14 | (0, 0.25, 0.50) | (0, 0.08, 0.33) | (0.08, 0.17, 0.42) | (0.17, 0.42, 0.67) | … | (0, 0.17, 0.42) | (0.17, 0.33, 0.58) | (0, 0, 0.25) | (0.17, 0.33, 0.58) |
| C15 | (0.08, 0.17, 0.42) | (0.42, 0.67, 0.92) | (0.75, 1,1) | (0.17, 0.25, 0.50) | … | (0.33, 0.58, 0.83) | (0, 0.17, 0.42) | (0,25 0,50 0.75) | (0, 0, 0.25) |

**Table 4** Normalized initial direct-relation fuzzy matrix

| | C1 | C2 | C3 | C4 | … | C12 | C13 | C14 | C15 |
|---|---|---|---|---|---|---|---|---|---|
| C1 | (0, 0, 0.02) | (0, 0.02, 0.04) | (0.01, 0.02, 0.04) | (0.06, 0.08, 0.09) | … | (0.01, 0.03, 0.05) | (0.06, 0.08, 0.09) | (0.02, 0.05, 0.07) | (0.01, 0.02, 0.04) |
| C2 | (0, 0.02, 0.05) | (0, 0, 0.02) | (0, 0.02, 0.04) | (0.02, 0.04, 0.06) | … | (0.02, 0.04, 0.06) | (0.06, 0.08, 0.09) | (0, 0.01, 0.03) | (0.02, 0.05, 0.07) |
| C3 | (0.02, 0.03, 0.05) | (0.03, 0.05, 0.06) | (0, 0, 0.02) | (0, 0.01, 0.03) | … | (0.02, 0.04, 0.06) | (0.07, 0.09, 0.09) | (0, 0.01, 0.03) | (0.07, 0.09, 0.09) |
| C4 | (0.07, 0.09, 0.09) | (0.05, 0.07, 0.08) | (0.02, 0.03, 0.05) | (0, 0, 0.02) | … | (0, 0.02, 0.04) | (0.06, 0.08, 0.09) | (0.03, 0.05, 0.08) | (0.02, 0.02, 0.05) |
| … | … | … | … | … | … | … | … | … | … |
| C12 | (0.02, 0.05, 0.07) | (0.02, 0.05, 0.07) | (0.01, 0.02, 0.04) | (0.01, 0.02, 0.04) | … | (0, 0, 0.02) | (0.03, 0.05, 0.08) | (0.02, 0.04, 0.06) | (0.05, 0.07, 0.08) |
| C13 | (0.06, 0.08, 0.09) | (0.04, 0.06, 0.08) | (0.05, 0.07, 0.09) | (0.07, 0.09, 0.09) | … | (0.01, 0.02, 0.05) | (0, 0, 0.02) | (0.02, 0.05, 0.07) | (0.02, 0.04, 0.06) |
| C14 | (0, 0.02, 0.05) | (0, 0.01, 0.03) | (0.01, 0.02, 0.04) | (0.02, 0.04, 0.06) | … | (0, 0.02, 0.04) | (0.02, 0.03, 0.05) | (0, 0, 0.02) | (0.02, 0.03, 0.05) |
| C15 | (0.01, 0.02, 0.04) | (0.04, 0.06, 0.08) | (0.07, 0.09, 0.09) | (0.02, 0.02, 0.05) | … | (0.03, 0.05, 0.08) | (0, 0.02, 0.04) | (0.02, 0.05, 0.07) | (0, 0, 0.02) |

**Table 5** Total-relation fuzzy matrix

| | C1 | C2 | C3 | C4 | ⋮ | C12 | C13 | C14 | C15 |
|---|---|---|---|---|---|---|---|---|---|
| C1 | (0.02, 0.06, 0.29) | (0.01, 0.05, 0.27) | (0.02, 0.05, 0.28) | (0.07, 0.13, 0.34) | ⋮ | (0.01, 0.06, 0.25) | (0.08, 0.15, 0.40) | (0.03, 0.08, 0.30) | (0, 0.06, 0.30) |
| C2 | (0.01, 0.06, 0.27) | (0.01, 0.03, 0.22) | (0.01, 0.05, 0.24) | (0.02, 0.07, 0.28) | ⋮ | (0.02, 0.06, 0.23) | (0.07, 0.12, 0.35) | (0, 0.04, 0.23) | (0, 0.08, 0.30) |
| C3 | (0.03, 0.08, 0.31) | (0.04, 0.08, 0.28) | (0.01, 0.05, 0.26) | (0.01, 0.06, 0.28) | ⋮ | (0.02, 0.07, 0.26) | (0.08, 0.15, 0.39) | (0.01, 0.05, 0.26) | (0.01, 0.14, 0.30) |
| C4 | (0.08, 0.15, 0.37) | (0.05, 0.11, 0.32) | (0.02, 0.07, 0.31) | (0.02, 0.06, 0.30) | ⋮ | (0, 0.05, 0.25) | (0.08, 0.16, 0.42) | (0.04, 0.10, 0.32) | (0, 0.07, 0.30) |
| ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ | ⋮ |
| C12 | (0.03, 0.08, 0.31) | (0.03, 0.08, 0.28) | (0.02, 0.05, 0.27) | (0.02, 0.06, 0.28) | ⋮ | (0, 0.02, 0.21) | (0.04, 0.10, 0.36) | (0.02, 0.07, 0.28) | (0.1, 0.10, 0.3) |
| C13 | (0.07, 0.14, 0.37) | (0.05, 0.10, 0.33) | (0.05, 0.11, 0.35) | (0.08, 0.14, 0.37) | ⋮ | (0.01, 0.05, 0.27) | (0.03, 0.08, 0.37) | (0.03, 0.09, 0.32) | (0, 0.09, 0.3) |
| C14 | (0.01, 0.05, 0.24) | (0, 0.03, 0.20) | (0.01, 0.04, 0.21) | (0.02, 0.06, 0.25) | ⋮ | (0, 0.03, 0.18) | (0.02, 0.06, 0.28) | (0, 0.02, 0.19) | (0, 0.05, 0.2) |
| C15 | (0.01, 0.05, 0.28) | (0.04, 0.09, 0.29) | (0.07, 0.12, 0.31) | (0.02, 0.06, 0.28) | ⋮ | (0.03, 0.07, 0.26) | (0.01, 0.07, 0.33) | (0.03, 0.07, 0.28) | (0, 0.04, 0.3) |

### 3.3 Causal and Effective Findings and Comments

Using the mathematical methodology detailed above, the graph showing the cause–effect relationship (Fig. 4) has been separated into two groups: the cause group and the effect group. The results and implications of the causes and effects of the diseases have been examined and interpreted below.

#### *3.3.1 Cause Factors*

Examining and interpreting the cause and effect groups we obtained is necessary for understanding the relationships among the 15 common diseases in internal medicine clinics. While investigating Fig. 4, C12 (Dyspepsia) has the highest $\tilde{r}i - \tilde{c}j$ value (0.46) among all the diseases in the cause group. This means that C12 impacts all the other diseases the most. Moreover, C7′s (Hyperlipidemia) $\tilde{r}i - \tilde{c}j$ value (0.43) makes it the second most crucial cause factor. The third most critical disease among all diseases is C3 (Anemia) with $\tilde{r}i - \tilde{c}j = 0.27$. This sequence continues with C4 (Hypertension/High blood pressure) and C11 (Heart failure). The other cause factors appear to have relatively moderate impacts on the other internal diseases.

#### *3.3.2 Effect Factors*

Influential effect factors can undoubtedly be easily affected by other diseases. Analyzing the effect factors (diseases) that could lead to critical consequences in the patients' dynamic disease processes may still be necessary. According to the cause-and-effect relation diagram depicted in Fig. 4, C13 (Renal failure) is clearly seen to have the highest $\tilde{r}i + \tilde{c}j$ value (4.82) among the effect factors group. Moreover, its influenced impact index $\tilde{c}j$ has the highest value (2.50) among the whole process. C13′s $\tilde{r}i - \tilde{c}j$Value also appears as an average value when taking the whole process into consideration. Furthermore, C15 (Malignancy) and C9 (Hepatitis) have incontrovertibly great influences on all the diseases as effect factors.

## 4 Results and Discussion

The presence of numerous diseases in internal medicine makes things difficult for physicians. Aside from the many diseases, the fact that diseases have inter-effects makes deciding on the perfect treatment more difficult for the physician. In a community study involving 27,000 people in the USA, one or more chronic diseases were seen in 50% of adults [43]. The increased number of chronic diseases in society and the relationship network associated with these diseases show the usefulness of fuzzy DEMATEL.

**Table 6** Defuzzified threshold values of T-matrix

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 0.12 | 0.11 | 0.12 | 0.18 | 0.12 | 0.12 | 0.15 | 0.14 | 0.12 | 0.11 | 0.18 | 0.11 | 0.21 | 0.14 | 0.13 |
| C2 | 0.11 | 0.09 | 0.10 | 0.12 | 0.12 | 0.10 | 0.09 | 0.10 | 0.10 | 0.08 | 0.11 | 0.10 | 0.18 | 0.09 | 0.10 |
| C3 | 0.14 | 0.14 | 0.11 | 0.12 | 0.13 | 0.16 | 0.10 | 0.13 | 0.16 | 0.11 | 0.15 | 0.11 | 0.21 | 0.10 | 0.13 |
| C4 | 0.20 | 0.16 | 0.13 | 0.13 | 0.14 | 0.12 | 0.15 | 0.15 | 0.12 | 0.11 | 0.20 | 0.10 | 0.22 | 0.15 | 0.15 |
| C5 | 0.12 | 0.12 | 0.12 | 0.12 | 0.08 | 0.12 | 0.09 | 0.10 | 0.11 | 0.08 | 0.13 | 0.08 | 0.13 | 0.09 | 0.10 |
| C6 | 0.10 | 0.09 | 0.13 | 0.11 | 0.09 | 0.09 | 0.08 | 0.10 | 0.15 | 0.08 | 0.12 | 0.08 | 0.17 | 0.10 | 0.12 |
| C7 | 0.19 | 0.10 | 0.11 | 0.17 | 0.12 | 0.12 | 0.09 | 0.14 | 0.12 | 0.09 | 0.18 | 0.11 | 0.20 | 0.12 | 0.12 |
| C8 | 0.11 | 0.09 | 0.09 | 0.10 | 0.07 | 0.08 | 0.08 | 0.08 | 0.08 | 0.10 | 0.10 | 0.07 | 0.14 | 0.08 | 0.08 |
| C9 | 0.12 | 0.09 | 0.12 | 0.11 | 0.10 | 0.15 | 0.12 | 0.10 | 0.09 | 0.11 | 0.15 | 0.09 | 0.15 | 0.10 | 0.11 |
| C10 | 0.08 | 0.07 | 0.09 | 0.09 | 0.07 | 0.07 | 0.07 | 0.11 | 0.09 | 0.06 | 0.08 | 0.07 | 0.12 | 0.07 | 0.08 |
| C11 | 0.18 | 0.12 | 0.14 | 0.17 | 0.13 | 0.15 | 0.15 | 0.13 | 0.15 | 0.10 | 0.13 | 0.10 | 0.20 | 0.17 | 0.15 |
| C12 | 0.14 | 0.13 | 0.11 | 0.12 | 0.12 | 0.10 | 0.10 | 0.14 | 0.13 | 0.10 | 0.14 | 0.08 | 0.17 | 0.12 | 0.13 |
| C13 | 0.20 | 0.16 | 0.17 | 0.20 | 0.12 | 0.18 | 0.12 | 0.16 | 0.15 | 0.12 | 0.19 | 0.11 | 0.16 | 0.15 | 0.15 |
| C14 | 0.10 | 0.08 | 0.09 | 0.11 | 0.07 | 0.08 | 0.08 | 0.09 | 0.08 | 0.07 | 0.13 | 0.07 | 0.12 | 0.07 | 0.08 |
| C15 | 0.11 | 0.14 | 0.17 | 0.12 | 0.12 | 0.14 | 0.09 | 0.12 | 0.13 | 0.10 | 0.11 | 0.12 | 0.14 | 0.12 | 0.12 |

**Table 7** Fuzzy values of $\tilde{r}_i$ , $\tilde{c}_j$ $\tilde{r}_i + \tilde{c}_j$, $\tilde{r}_i - \tilde{c}_j$

| | $\tilde{r}_i$ | $\tilde{c}_j$ | $\tilde{r}_i + \tilde{c}_j$ | $\tilde{r}_i - \tilde{c}_j$ |
|---|---|---|---|---|
| C1 | (0.44, 1.19, 4.46) | (0.45, 1.20, 4.38) | (0.89, 2.39, 8.84) | (− 3.93, − 0.01, 4.01) |
| C2 | (0.22, 0.86, 3.80) | (0.29, 0.89, 3.85) | (0.51, 1.75, 7.64) | (− 3.63, − 0.04, 3.51) |
| C3 | (0.52, 1.24, 4.39) | (0.35, 0.96, 4.03) | (0.87, 2.21, 8.42) | (− 3.51, 0.28, 4.04) |
| C4 | (0.54, 1.37, 4.77) | (0.46, 1.15, 4.27) | (1.00, 2.52, 9.04) | (− 3.73, 0.22, 4.31) |
| C5 | (0.23, 0.82, 3.78) | (0.24, 0.81, 3.74) | (0.47, 1.63, 7.52) | (− 3.50, 0.00, 3.54) |
| C6 | (0.28, 0.86, 3.74) | (0.35, 1.00, 4.03) | (0.63, 1.86, 7.78) | (− 3.75, − 0.14, 3.40) |
| C7 | (0.44, 1.16, 4.35) | (0.25, 0.80, 3.61) | (0.69, 1.96, 7.96) | (− 3.17, 0.35, 4.10) |
| C8 | (0.14, 0.63, 3.25) | (0.30, 0.99, 4.07) | (0.44, 1.62, 7.32) | (− 3.93, − 0.36, 2.95) |
| C9 | (0.28, 0.92, 4.02) | (0.30, 0.98, 4.09) | (0.58, 1.90, 8.11) | (− 3.80, − 0.05, 3.72) |
| C10 | (0.14, 0.53, 3.01) | (0.15, 0.69, 3.41) | (0.29, 1.21, 6.42) | (− 3.28, − 0.16, 2.86) |
| C11 | (0.47, 1.29, 4.69) | (0.47, 1.25, 4.62) | (0.94, 2.53, 9.31) | (− 4.15, 0.04, 4.22) |
| C12 | (0.33, 1.01, 4.25) | (0.16, 0.66, 3.39) | (0.49, 1.67, 7.64) | (− 3.06, 0.35, 4.09) |
| C13 | (0.59, 1.44, 4.95) | (0.69, 1.59, 5.21) | (1.28, 3.02, 10.1) | (− 4.62, − 0.15, 4.26) |
| C14 | (0.14, 0.64, 3.28) | (0.27, 0.89, 3.87) | (0.42, 1.53, 7.16) | (− 3.73, − 0.25, 3.01) |
| C15 | (0.37, 1.01, 4.17) | (0.42, 1.10, 4.34) | (0.78, 2.11, 8.50) | (− 3.97, − 0.09, 3.75) |

In our study, we have successfully applied the fuzzy DEMATEL method to reduce the complexity of the relationships among many diseases. Using the fuzzy DEMATEL technique, dyspepsia appears as the main cause factor. When a patient using medication for dyspepsia comes to an internal medicine outpatient clinic, the physician thinks of two different profiles, the first being obesity accompanied by unhealthy dietary habits and the second being involuntarily weight loss. Hypertension, hyperlipidemia, diabetes mellitus, and coronary artery disease are common concomitant diseases when we think of obese and dyspeptic patients. Malignancy first comes to mind for a patient with dyspepsia and weight loss. When considering dyspepsia treatment, while cause-oriented treatments are planned in organic pathologies, changing dietary habits significantly reduces patients' complaints in functional dyspepsia. One common cause of dyspepsia is dietary incompatibility, which is the natural end result of obesity and hyperlipidemia.

The second most common cause in our study is hyperlipidemia. Nowadays, the risk of hyperlipidemia and obesity has increased with decreases in physical activity and increases in the consumption of animal products; as a result, the frequency of hypertension, diabetes mellitus, and coronary artery disease has increased. Hyperlipidemia causes the vascular system disorder known as atherosclerosis in that it leads to lipid accumulations under the intima layer of vessels. Atherosclerosis is the main factor causing

**Table 8** Crisp values of $\tilde{r}_i$ , $\tilde{c}_j$ $\tilde{r}_i + \tilde{c}_j$, $\tilde{r}_i - \tilde{c}_j$

| | $\tilde{r}_i$ | $\tilde{c}_j$ | $\tilde{r}_i + \tilde{c}_j$ | $\tilde{r}_i - \tilde{c}_j$ |
|---|---|---|---|---|
| C1 | 2.03 | 2.01 | 4.04 | 0.02 |
| C2 | 1.62 | 1.68 | 3.30 | − 0.05 |
| C3 | 2.05 | 1.78 | 3.83 | 0.27 |
| C4 | 2.23 | 1.96 | 4.19 | 0.26 |
| C5 | 1.61 | 1.60 | 3.20 | 0.01 |
| C6 | 1.63 | 1.79 | 3.42 | − 0.16 |
| C7 | 1.98 | 1.56 | 3.54 | 0.43 |
| C8 | 1.34 | 1.79 | 3.13 | − 0.45 |
| C9 | 1.74 | 1.79 | 3.53 | − 0.05 |
| C10 | 1.23 | 1.42 | 2.64 | − 0.19 |
| C11 | 2.15 | 2.11 | 4.26 | 0.04 |
| C12 | 1.86 | 1.40 | 3.27 | 0.46 |
| C13 | 2.33 | 2.50 | 4.82 | − 0.17 |
| C14 | 1.36 | 1.68 | 3.03 | − 0.32 |
| C15 | 1.85 | 1.95 | 3.80 | − 0.10 |

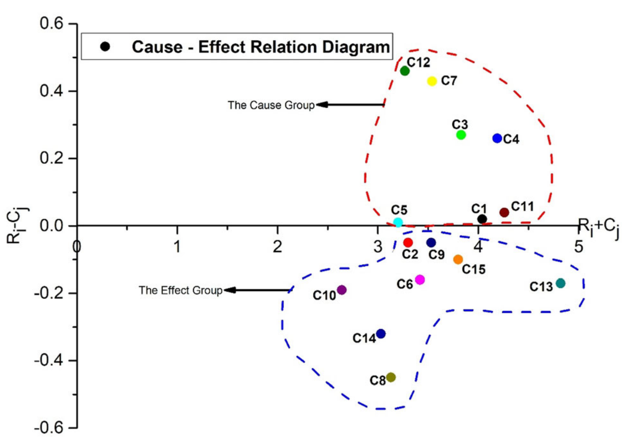


**Fig. 4** Cause–effect relation diagram

coronary artery disease. In addition to atherosclerosis, hyperlipidemia causes diseases such as hepatosteatosis and pancreatitis. Exercise, diet modification, and medication (statin, fibrate, etc.) are included in hyperlipidemia treatments.

The third most common reason is anemia. The most common cause of anemia is iron deficiency, and with varying rates in different regions of the world. This rate has been found up to nearly 40.9% in young women between the ages of 18 and 25 [44]. Iron is carried along in the blood with the carrier protein called transferrin, and it is most commonly found in the form of hemoglobin. The most important function of iron is to reversibly bind oxygen in the center of the body's oxygen-carrying hemeproteins. Severe anemia affects all bodily systems as well as produces excessive tiredness, shortness of breath, and cardiac arrhythmias. Pre-menopausal women without alarming symptoms are primarily interpreted in favor of menstrual bleeding. When a patient with iron-deficiency anemia has no menstruation complaints, gastrointestinal malignancies should also be considered. Anemia is considered pathological in post-menopausal women and men of all ages; radiological and endoscopic imaging should be performed. Treatment is focused on the cause; if no organic reason is present, iron preparations are given to the patients. The fourth most common reason is hypertension. Hypertension is the number one risk factor among preventable causes of death in the world. Hypertension is a main cause of heart and kidney failure and can be prevented with lifestyle changes and antihypertensive medications.

When defining the effect group, the first three are seen to be renal failure, malignancy, and hepatitis. Almost all organs and systems are agreed to be affected by kidney failure. As the kidneys have functions like regulating the acid–base balance, eliminating metabolic waste, regulating blood pressure, and stimulating erythrocyte production, renal failure has the greatest effect on other diseases [45]. In chronic renal failure, anemia is one of the most important reasons limiting the daily-life activities and productivity of patients with chronic renal failure. Generally when the glomerular filtration value drops below 30–35 ml/min, the hematocrit begins to decrease. An important factor that increases the tendency for bleeding in chronic kidney failure is platelet dysfunction. When renal failure develops, secondary hyperparathyroidism develops due to phosphate accumulations in the blood. Congestive heart failure and cardiomyopathy are the most important causes of death in these patients. Renal replacement treatments are given in patients with chronic renal failure when the glomerular filtration value falls below 10 ml/min.

The second major disease in the effect group is malignancy. Tumor cells can affect the entire metabolism by disrupting organ functions or through paraneoplastic side effects. The mechanical effects of malignancy result from how it affects the related organ's function. If the malignancy involves a lung, it shows respiratory effects by creating pressure on the surrounding tissues or reducing lung capacity. As opposed to mechanical effects, bioactive products secreted by tumors are effective at disrupting organ functions. This condition, called paraneoplastic syndrome, may affect the body as it can involve the hematological, cardiovascular, immunological, and neuromuscular systems. Depending on the type and stage of malignancy, treatments such as surgery, chemotherapy, radiotherapy, and immunological treatment options are considered. Furthermore, hepatitis (viral, toxic, or autoimmune) is found third in the effect group, which is not surprising because the liver has significant functions on metabolisms such as enzyme and hormone synthesis, drug excretion, and coagulation mechanisms. Because a significant portion of drugs are metabolized in the liver, drug levels can be toxic and affect all organs in cases of hepatitis and liver failure. Bleeding, petechia, and purpura can be seen as secondary symptoms of coagulation mechanism malfunctions. In cases where liver functions are severely impaired, hepatorenal and hepatopulmonary syndromes can be seen. Regarding treatment, some patients with viral hepatitis are treated with antiviral therapy. Abstaining from toxic substances is the treatment of choice in toxic hepatitis, and starting immunosuppressive therapy is the treatment of choice in autoimmune hepatitis. Patients are evaluated for liver transplants in the case of liver failure.

## 5 Conclusion

In this study, the cause–effect relationships of frequently encountered internal medicine diseases were revealed by fuzzy DEMATEL method. In addition, general treatment/prevention processes related to diseases are included. This study provides an overview as a method for evaluating patients with multiple diseases. By increasing the number of internists, a comprehensive view average can be obtained. For future studies, the authors intend to continue improving and adapting the methodology for evaluating diseases for various fields of medicine. From the methodological point of view, comparisons of novel methods that integrate with various versions of fuzzy set theory (i.e., Pythagorean fuzzy sets, interval type-2 fuzzy sets, hesitant fuzzy sets, intuitionistic fuzzy sets, and stochastic fuzzy sets) can be carried out over existing studies. As a result, the contribution of this study to the internal medicine field can be considered admirable. We think the fuzzy DEMATEL method will yield new vision in modern medicine for understanding the interrelationships among multiple diseases.

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**Compliance with Ethical Standards**

**Conflict of interest** The authors declare that they have no competing interests. This research did not receive any specific grant. No funding used. No conflict of interest declared.

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