Identifying Factors in Congenital Heart Disease Transition using Fuzzy DEMATEL

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***Abstract*—The transition from pediatric to adult cardiology care is a pivotal moment in the healthcare journey of individuals with congenital heart conditions or childhood-onset heart diseases. This multifaceted process requires meticulous consideration of clinical, psychosocial, and logistical factors. This research aims to explore the critical criteria for transitioning pediatric patients to adult cardiology, delving into the challenges and opportunities inherent in this healthcare shift. The identified factors for successful transition, including age and developmental stage, medical complexity, cardiac function, psychosocial factors, insurance, and financial considerations, play integral roles in the transition process. Leveraging analytical methodologies, particularly the Fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL), this study involves three experts who assess criteria linguistically, converted to Triangular Fuzzy Numbers, and averaged. Defuzzification, using the CFCS method, yields crisp values. Results reveal that Medical Complexity (U+V = 3.96, U-V = 0.233), Insurance (U+V = 3.931, U-V = 0.22), Psychosocial Factors (U+V = 3.839, U-V = 0.387), and Age and Developmental Stage (U+V = 3.802, U-V = 0.106) follow Cardiac Function (U+V = 4.312, U-V = 0.946) in ranking. Age and Developmental Stage, Medical Complexity, Psychosocial Factors, and Insurance are considered causal variables, with Cardiac Function as an effect. These numerical insights enhance our understanding of transition criteria interdependencies, informing tailored healthcare strategies.**

Keywords*—*DEMATEL; Fuzzy DEMATEL; factors; pediatric patients; heart disease

I. INTRODUCTION

Congenital Heart Disease (CHD) is a complex and diverse group of cardiovascular conditions that affect a substantial number of children worldwide. The remarkable advancements in medical care, surgical interventions, and early diagnosis have significantly improved the survival rates of pediatric patients born with CHD. As a result, more and more of these individuals are now moving from receiving care in cardiology to adult cardiology as they enter adolescence and early adulthood. This shift, in healthcare can be sometimes difficult phase for them. It's essential to transition patients with congenital heart disease (CHD) into adult cardiology care to ensure that they continue to receive effective treatment, monitoring and support. However, this process is complex. Its outcome has an impact, on the long-term health and quality of life of these patients.

The transition covers aspects, such, as medical considerations, psychological and social factors, communication and involving both patients and their families. This study builds on the work of researchers [1, 2] a review by [3] and the guidelines provided in the literature to further understand how pediatric patients with heart disease move from pediatric care to adult care. By using the Fuzzy DEMATEL approach our goal is to identify the factors that influence this transition. This information can then be used by healthcare providers, policymakers and stakeholders to improve the quality of care and long-term outcomes, for this group of patients. As we strive for a patient centered transition model, the importance of utilizing tools has become more recognized. This research aims to address the urgency of identifying and prioritizing the key determinants that influence the transition of CHD pediatric patients into adolescents. This research makes a significant contribution to the field of pediatric cardiology by applying the Fuzzy DEMATEL approach to unravel the intricate dynamics of transitioning pediatric patients with CHD to adolescence. By utilizing this advanced analytical tool, the study aims to provide a nuanced understanding of the critical factors influencing the transition process. This study's contribution lies in its potential to identify, quantify, and prioritize the key elements that impact the successful transition of pediatric CHD patients to adult care. The outcomes are expected to go beyond traditional analyses, offering insights into the fuzzy relationships among various transition criteria. Such insights can inform tailored strategies for healthcare providers, policymakers, and stakeholders to optimize the transition process. These findings can be used to develop more effective transition procedures and strategies, thereby improving the quality and outcomes of care for this vulnerable population. The outcomes of this study hold the potential to transform the landscape of pediatric-to-adolescent transition care, offering hope and improved prospects for those living with congenital heart disease. This paper is organized as follows: Literature review is presented in Section II, Section III discusses scaffold of methodologies, in Section IV discussion about the results is made and finally Section V concludes the paper.

II. LITERATURE REVIEW

The Decision-making Trial and Evaluation Laboratory (DEMATEL) method is a widely used multicriteria decision-making method [4]. It is used to evaluate the relationships between factors in various fields [5]. DEMATEL helps to extract the complex structure of a problem by identifying cause-and-effect relationships among different elements [6]. It is used to model the understandable structure of a complex system and measure the complexity of a problem [7]. DEMATEL can be applied to both small and simple systems as well as complex systems [8]. The aim of [9] is to provide a solution to the issues mentioned above. Several barriers impede blockchain adoption, including system-related, external, intra-organizational, and inter-organizational ones. The research in [10] looks at the obstacles that stand in the way when it comes to assessing blockchain life cycles in China. There has been no research to scrutinize how these barriers cooperate to improve decision-making in life cycle assessments. In a study by [11] identify critical bottlenecks in the development of the HRS in China using a customized Fuzzy DEMATEL method. It is suggested by the authors of [12], that a Fuzzy trapezoidal approach should be employed to prioritize software requirements. Various Fuzzy logic-based approaches for prioritizing software requirements are discussed in [13]. The study in [14] suggests a new version of the fuzzy DEMATEL that uses PFS for language variables. The research in [15] focuses on establishing a logical framework for strategy maps; inserting subjectivity into the overall strategy formulation process; identifying the most important connections between strategy objectives to make the route map clear, useful, and easy to understand; and combining qualitative and quantitative methods to make a strong and complete solution.

III. Theoretical Background

A. Fuzzy Logic

Fuzzy logic is a mathematical framework that contracts with vagueness besides imprecision in decision-making and control systems. It is an extension of binary logic that is based on true and false. It was first proposed in the early 1960s by the Iranian mathematician Lotfi Zadeh. Fuzzy logic allows for degrees of truth, which makes it particularly useful in situations where information is vague, ambiguous, or incomplete.

Definition 1: A triangular fuzzy number, also known as a TFN is defined by a membership function that assigns degrees of membership (degrees of truth) to values, within a given range. The membership function of a triangular number takes the shape of a triangle and determined by three parameters; the lower bound (a) the upper bound (b) and the peak (c). We can express a triangular number using the equation:

$$\mu\_A(x) = \begin{cases} 0, & \text{if } x < u, \\ (x - u) / (w - u & \text{if } u \leq x < w, \\ (v - x) / (v - w), & \text{if } w \leq x < v, \\ 0, & \text{if } x \geq v \end{cases} \quad (1)$$

where, $\mu\_A(x)$ is the degree of membership (or membership value) of value x to the triangular fuzzy number A. Where u is a lower bound, v an upper one, and w is the peak. This function defines the degree of membership for any provided value x within [u, v].

Definition 2: When working with two Triangular Fuzzy Numbers (TFNs) we perform operations to combine or manipulate these sets. Let us take two TFNs, A and B and their membership functions defined as follows:

For TFN A:

$$\mu\_A(x) = \begin{cases} 0, & \text{if } x < u1, \\ (x - u1) / (c1 - u1), & \text{if } u1 \leq x < w1, \\ (v1 - x) / (v1 - w1), & \text{if } w1 \leq x \leq v1, \\ 0, & \text{if } x > v1 \end{cases}$$

For TFN B:

$$\mu\_B(x) = \begin{cases} 0, & \text{if } x < u2, \\ (x - u2) / (w2 - u2), & \text{if } u2 \leqslant x < w2, \\ (v2 - x) / (v2 - w2), & \text{if } w2 \leqslant x \leqslant v2, \\ 0, & \text{if } x > b2 \end{cases}$$

1) *Basic operations:*

a) Addition of TFNs (U + V): To add two TFNs together you we add their membership values pointwise. The resulting TFN, denoted as C (U + V) can be represented by the following membership function:

$$\mu\_W(x) = \max(\mu\_U(x) + \mu\_V(x)) \quad (2)$$

where, $\mu\_W(x)$ represents the degree of membership of x to the resulting TFN W.

b) Subtraction of TFNs (U - V): The subtraction of two TFNs is performed by subtracting the membership values of the second TFN (V) from the membership values of the first TFN (U). The resulting TFN, W (U - V), has a membership function as follows:

$$\mu\_W(x) = \max(\mu\_U(x) - \mu\_V(x)) \quad (3)$$

*c) Multiplication of TFNs (U * V):* Multiplication of two TFNs is done by taking the product of their membership values at each point. Let W (U * V) be the resulting TFN function as follows:

$$\mu\_W(x) = \mu\_U(x) * \mu\_V(x) \quad (4)$$

d) Division of TFNs (U / V): The division of two TFNs is performed by dividing their membership values pointwise. The resulting TFN, W (U / V), has a membership function (for $\mu\_V(x) > 0$) as follows:

$$\mu\_W(x) = \mu\_U(x) / \mu\_V(x) \quad (5)$$

B. DEMATEL Method

The DEMATEL methodology provides an approach, for analyzing the cause-and-effect relationship of factors in complex decision-making problems [16]. It aims to understand how these factors are interconnected and their impact, on each other. This methodology is commonly employed in management, engineering and social sciences.

1) *DEMATEL Steps:*

a) Constructing a Causal Diagram (Impact Matrix): First, a causal diagram or an impact matrix is constructed for DEMATEL. The criterion measured is represented by the rows and columns of this matrix. The components of the matrix, labeled a_ij, depict the effect of directionality (or impact) of element i upon element j. The impact values can be determined based on expert opinions, surveys, or data analysis.

b) Normalization of the Impact Matrix: To ensure that the impact values are within a common scale, the impact matrix remains normalized. This is done by dividing each row of the matrix by the sum of its absolute values. The normalized matrix is denoted as N.

$$Z\_ij = |a\_ij| / \Sigma|a\_ij| \quad (\forall j) \tag{6}$$

where, Z_ij stands the normalized impact value of factor i on factor j.

c) Calculation of Total Influences: DEMATEL calculates the total influence of each factor by summing the normalized values in the corresponding row of the normalized impact matrix as shown in the below equation.

$$TI\_i = \Sigma Z\_ij \quad (\forall j) \tag{7}$$

where, TI_i is the total influence of factor i.

d) Division into cause-and-effect groups: Grounded on the total influence values, factors are categorized into two clusters: cause and effect. Since these were found to affect each other directly, and hence interchangeably we can say all had ‘‘cause’’ and ‘‘effect” attributes.

e) Drawing the Causal Diagram: A causal diagram is created to visually represent the cause-and-effect relationships among factors. This diagram shows how factors influence each other and helps in understanding the structure of the problem.

f) Interpreting the Results: The DEMATEL results are interpreted to determine the key elements, that plays an important role in the issue at consideration. Additionally, the method provides insights into the direction besides the strength of the causal associations.

C. Fuzzy DEMATEL (FDEMATEL) Method

FDM is an extension of the traditional DEMATEL technique that incorporates the concepts of fuzzy logic to handle vagueness besides imprecision in decision-making and problem-solving. DEMATEL is a technique employed in the analysis and visualization of the causal relationships between various elements in intricate systems. FDM, therefore, adds a layer of fuzziness to these relationships to better reflect real-world situations where relationships are not always clear-cut. The assessment of key determinants of congenital cardiac disease in young adults during the transitional period from adolescence to adulthood requires a collaborative decision-making approach. By interacting among various experts, a satisfactory decision is reached in a collective decision. Humans commonly criticize based on their experiences and insights in such a group decision-making process. As such, these decisions are made in an uncertain situation, and their expressions are more likely to be ambiguous than crisp. Consequently, the DEMATEL method cannot directly identify critical factors under these circumstances, requiring an extended DEMATEL method based on fuzzy set theory.

Step 1: The Fuzzy Direct Relation Matrix (FDRM) generation

To figure out how the n criteria relate to each other, we first make a matrix called n × n. Each element in every row in the matrix affects the element in each column in the matrix, and this can be represented by a fuzzy number. In the event of a matrix composed of the opinions of multiple experts, all experts must complete the matrix; the arithmetic mean of the opinions of all experts is used to construct the matrix z.

$$z = \begin{bmatrix} 0 & \cdots & \tilde{z}_{n1} \\ \vdots & \ddots & \vdots \\ \tilde{z}_{1n} & \cdots & 0 \end{bmatrix} \tag{8}$$

Step 2: The fuzzy direct-relation matrix normalization

The formula shown in Eq. (9) is used to compute the normalized fuzzy direct-relation matrix.

$$\tilde{a}_{ij} = \frac{\tilde{z}_{ij}}{r} = \left(\frac{m_{ij}}{r}, \frac{n_{ij}}{r}, \frac{o_{ij}}{r}\right) \tag{9}$$

Where,

$$r = \max_{i,j}\left\{\max_i \sum_{j=1}^{n} o_{ij}, \max_j \sum_{i=1}^{n} o_{ij}\right\} \quad i,j \in \{1,2,3,\dots,n\}$$

Step 3: The fuzzy total-relation matrix (TRM) is computed by the following formula:

$$\widetilde{TR} = \lim_{k\to+\infty}(\tilde{a}^1 \oplus \tilde{a}^2 \oplus \dots \oplus \tilde{a}^k) \tag{10}$$

In the fuzzy total-relation matrix, the function of each element is expressed as $\tilde{t}_{ij} = (m''_{ij}, n''_{ij}, o''_{ij})$ and is generated as,

$$[m''_{ij}] = a_m \times (I - a_m)^{-1}$$

$$[n''_{ij}] = a_n \times (I - a_n)^{-1}$$

$$[o''_{ij}] = a_o \times (I - a_o)^{-1}$$

In the case of a normalized matrix, the initial step is to identify the inverse of the standardized matrix. Subsequently, the inverse of matrix I is extracted and multiplied by the normalized matrix.

Step 4: Defuzzification for Crisp Values Generation

A crisp value of the TRM has been obtained using the CFCS. The CFCS method is as follows:

$$m_{ij}^n = \frac{(m_{ij}^t - min\, m_{ij}^t)}{\Delta_{min}^{max}} \tag{11}$$

$$n_{ij}^n = \frac{(n_{ij}^t - min\, m_{ij}^t)}{\Delta_{min}^{max}} \tag{12}$$

$$o_{ij}^n = \frac{(o_{ij}^t - min\, m_{ij}^t)}{\Delta_{min}^{max}} \tag{13}$$

So that,

$$\Delta_{min}^{max} = \max o_{ij}^t - \min m_{ij}^t \tag{14}$$

Computing the normalized upper and lower bounds values:

$$m_{ij}^s = \frac{n_{ij}^n}{(1 + n_{ij}^n - m_{ij}^n)} \tag{15}$$

$$o_{ij}^{s} = \frac{o_{ij}^{n}}{(1+ o_{ij}^{n} - m_{ij}^{n})} \quad (16)$$

The crisp value is the result of the CFCS algorithm.

The normalized crisp values:

$$x_{ij} = \frac{[l_{ij}^{s}\left(1-l_{ij}^{s}\right)+u_{ij}^{s}\times u_{ij}^{s}]}{[1-l_{ij}^{s}+u_{ij}^{s}]} \quad (17)$$

Step 5: Threshold value

The threshold values are crucial in determining the internal relations matrix. As a result, NRMs are plotted by disregarding the partial relationships are disregarded. In the NRM, only those relationships with greater values than a threshold value in matrix TR are included. To calculate a threshold value for a given relationship, it suffices to calculate its average values from the matrix TR. Once the threshold intensity has been determined, all the values of matrix TR that are less than the threshold are set to 0, i.e., the causal relationship mentioned above is disregarded. For example, the matrix TR value is disregarded if the threshold value is 0.3970.

Step 6: Final result besides forming a causal relation diagram.

The subsequent step is to calculate the total of the rows and columns of TR (Step 4). The total of the rows (U) and columns (V) can be derived as follows:

$$U = \sum_{j=1}^{n} TR_{ij} \quad (18)$$

$$V = \sum_{i=1}^{n} TR_{ij} \quad (19)$$

Subsequently, the U and V determine the values of U+V and U-V.

Empirical Study: The fuzzy DEMATEL approach was used to extract all the dominant factors while transitioning from congenital heart disease to adulthood.

Step 1: The study identified five important dominant factors as tabulated in Table I. The study considers three experts providing a direct impact on each of the dominant factors in terms of linguistic assessment, the linguistic terminology with their respective TFNs is depicted in Table II.

Step 2: DRMs provided by experts

The linguistic terminology mentioned by all three experts are converted into corresponding TFNs are tabulated in Table III to Table V and the arithmetic mean of all the three Tables is shown in Table VI.

Step 3: Normalize the Fuzzy DRM as per Eq. (9) and the normalized DRM is tabulated as shown in Table VII. Also, the fuzzy TRM is calculated as the Eq. (10) and is shown in Table VIII.

Step 4: Defuzzify into crisp values and threshold values: Total normalized crisp values are calculated as per Eq. (17) and are shown in Table IX. As mentioned in Step 5 of Section 3.3 the threshold value for this study is set to 0.3970. Table X describes the model of important relations.

TABLE I. DOMINANT FACTORS (DF)

Factor	Explanation
DF1	Age and Developmental Stage: Determine the appropriate age for transition, considering both chronological age and developmental maturity. Some patients may be ready for transition earlier or later based on their circumstances
DF2	Medical Complexity: Evaluate the complexity of the patient's heart condition. Patients with complex congenital heart defects or ongoing medical issues may require specialized adult cardiology care
DF3	Cardiac Function: Assess the current cardiac function and stability of the patient. This includes evaluating factors like ejection fraction, valve function, and the need for ongoing interventions or surgeries.
DF4	Psychosocial Factors: Consider the patient's psychosocial well-being and readiness for transition. Assess their understanding of their condition, self-management skills, and emotional preparedness for adult care.
DF5	Insurance: Address insurance coverage and financial considerations. Verify that the patient's insurance plan will cover adult cardiology care and that there are no disruptions in coverage during the transition

TABLE II. LINGUISTIC TERMINOLOGY WITH THEIR TFNS

Linguistic terms	M	N	O
No influence	1	1	1
Very low influence	2	3	4
Low influence	4	5	6
High influence	6	7	8
Very high influence	8	9	9

TABLE III. FIRST EXPERT DRM

	DF1	DF2	DF3	DF4	DF5
DF1	0	2	5	3	3
DF2	2	0	4	3	4
DF3	2	2	0	3	4
DF4	5	2	3	0	4
DF5	1	5	5	3	0

TABLE IV. SECOND EXPERT DRM

	DF1	DF2	DF3	DF4	DF5
DF1	0	2	4	2	2
DF2	3	0	5	3	4
DF3	1	3	0	4	2
DF4	4	5	4	0	3
DF5	4	3	5	2	0

TABLE V. THIRD EXPERT DRM

	DF1	DF2	DF3	DF4	DF5
DF1	0	4	4	5	2
DF2	3	0	5	2	3
DF3	5	3	0	2	1
DF4	3	1	3	0	4
DF5	3	4	5	1	0

Step 5: Output and CR diagram

As per Eq. (18) and Eq. (19) the concluding output is computed and shown in Table XI.

The model of significant relationships is illustrated in Fig. 1, which can be visualized as a graph, with the values of (U+V) and (U-V) positioned on the horizontal and vertical axes respectively. The coordinate system determines the positions and relationships of each factor to a given point in the coordinate system.

IV. Results and Discussion

By Fig. 1 and Table XI, each DF was assessed based on the following elements:

- The U + V horizontal vector indicates the importance of each factor within the system. More specifically, it indicates the effect of factor I within the system and the effect of other system factors within the system on the factor. Cardiac Function is the ranking factor in terms of importance, followed by Medical Complexity, insurance, psychosocial factors, age and development stage, and insurance. Age and development stage are considered causal variables in this study, while Cardiac Function is considered an effect.
- The vertical vector U-V represents the extent to which a factor influences a system. In cases a positive U-V indicates the cause while a negative U-V suggests the effect. In this study cardiac function emerges as the factor determining importance followed by factors, like medical complexity, insurance, psychosocial aspects, age and development stage, in descending order of significance.

Table VII presents the Normalized Fuzzy DRM, a decision-making matrix that has been normalized to facilitate a comprehensive analysis of the relationships between the identified factors (DF1, DF2, DF3, DF4, and DF5). The entries in the matrix are represented as fuzzy numbers, denoted by (lower bound, mean, upper bound), capturing the uncertainty and imprecision in the decision-making process. The fuzzy numbers in each cell represent the normalized influence of the corresponding row factor on the column factor. The lower and upper bounds capture the range of possible influence, while the mean value provides a central tendency. Table VIII extends the analysis by presenting the Fuzzy Total Relation, which aggregates the normalized influences from Table VII to provide a holistic view of the overall relationships between the factors.

Table IX presents the crisp TRM, a triangular fuzzy relationship matrix, for the identified factors in the study. The matrix is symmetric, with each cell indicating the degree of relationship strength between two factors. the values within the matrix range between 0 and 1, representing the intensity of the relationship. Higher values indicate stronger relationships, while lower values suggest weaker relationships. The diagonal elements of the matrix are typically 1, indicating the self-relationship of each factor. This matrix provides a quantitative representation of the fuzzy relationships among the factors under consideration.

TABLE VI. Arithmetic Mean of Expert DRMs

	DF1	**DF2**	**DF3**	**DF4**	**DF5**
DF1	(0.00,0.00,0.00)	(3.33,4.33,5.33)	(6.66,7.66,8.33)	(4.66,5.66,6.33)	(2.66,3.66,4.66)
DF2	(3.33,4.33,5.33)	(0.00,0.00,0.00)	(7.33,8.33,8.67)	(3.33,4.33,5.33)	(5.33,6.33,7.33)
DF3	(3.67,4.33,4.67)	(3.33,4.33,5.33)	(0.00,0.00,0.00)	(4.00,5.00,6.00)	(3.00,3.66,4.33)
DF4	(6.00,7.00,7.67)	(3.67,4.33,4.67)	(4.67,5.67,6.67)	(0.00,0.00,0.00)	(5.33,6.33,7.33)
DF5	(3.67,4.33,5.00)	(6.00,7.00,7.67)	(8.00,9.00,9.00)	(2.33,3.00,3.67)	(0.00,0.00,0.00)

TABLE VII. Normalized Fuzzy DRM

	DF1	**DF2**	**DF3**	**DF4**	**DF5**
DF1	(0.00,0.00,0.00)	(0.10,0.13,0.16)	(0.20,0.23,0.25)	(0.14,0.17,0.19)	(0.08,0.11,0.14)
DF2	(0.10,0.13,0.16)	(0.00,0.00,0.00)	(0.22,0.25,0.26)	(0.10,0.13,0.16)	(0.16,0.19,0.22)
DF3	(0.11,0.13,0.14)	(0.10,0.13,0.16)	(0.00,0.00,0.00)	(0.12,0.15,0.18)	(0.09,0.11,0.13)
DF4	(0.18,0.21,0.23)	(0.11,0.13,0.14)	(0.14,0.17,0.20)	(0.00,0.00,0.00)	(0.16,0.19,0.22)
DF5	(0.11,0.13,0.15)	(0.18,0.21,0.23)	(0.24,0.27,0.27)	(0.07,0.09,0.11)	(0.00,0.00,0.00)

TABLE VIII. Fuzzy Total Relation

	DF1	**DF2**	**DF3**	**DF4**	**DF5**
DF1	(0.13,0.24,0.43)	(0.21,0.36,0.58)	(0.36,0.54,0.79)	(0.24,0.38,0.58)	(0.20,0.34,0.57)
DF2	(0.23,0.38,0.60)	(0.14,0.26,0.47)	(0.40,0.59,0.84)	(0.21,0.36,0.58)	(0.27,0.42,0.61)
DF3	(0.21,0.32,0.49)	(0.19,0.32,0.51)	(0.16,0.30,0.50)	(0.20,0.32,0.51)	(0.19,0.31,0.50)
DF4	(0.30,0.44,0.65)	(0.24,0.38,0.59)	(0.34,0.54,0.80)	(0.13,0.25,0.44)	(0.28,0.42,0.65)
DF5	(0.24,0.37,0.57)	(0.30,0.44,0.64)	(0.42,0.60,0.82)	(0.19,0.33,0.53)	(0.14,0.26,0.45)

TABLE IX. THE CRISP TRM

	DF1	DF2	DF3	DF4	DF5
DF1	0.27	0.378	0.554	0.388	0.364
DF2	0.394	0.293	0.596	0.376	0.437
DF3	0.342	0.343	0.326	0.342	0.33
DF4	0.452	0.4	0.548	0.274	0.439
DF5	0.389	0.449	0.605	0.347	0.285

TABLE X. THE CRISP TRM INCLUSIVE OF THE THRESHOLD VALUE

	DF1	DF2	DF3	DF4	DF5
DF1	0	0	0.554	0	0
DF2	0	0	0.596	0	0.437
DF3	0	0	0	0	0
DF4	0.452	0.4	0.548	0	0.439
DF5	0	0.449	0.605	0	0

Table X extends the Crisp TRM by incorporating a threshold value to highlight significant relationships. In this modified matrix, values below the threshold are set to 0, indicating negligible or weak relationships, while values equal to or above the threshold are retained. This thresholding process simplifies the matrix by emphasizing only the most impactful relationships, making it easier to interpret and focus on the key interactions.

TABLE XI. FINAL RESULT

	V	U	U+V	U-V
Age and Developmental Stage	1.848	1.954	3.802	0.106
Medical Complexity	1.863	2.096	3.96	0.233
Cardiac Function	2.629	1.683	4.312	0.946
Psychosocial Factors	1.726	2.113	3.839	0.387
Insurance	1.856	2.075	3.931	0.22

Table XI presents the final results of the study, providing a comprehensive assessment of the identified factors in the context of the transition from pediatric patients with congenital heart disease to adolescence. The Table includes four columns: V, U, U+V, U-V.

Age and Developmental Stage: This factor is assigned values for each of the four metrics: V (1.848), U (1.954), U+V (3.802), U-V (0.106).

Medical Complexity: Similarly, this factor is assessed with values for V (1.863), U (2.096), U+V (3.96), U-V (0.233).

Cardiac Function: The values for this factor are V (2.629), U (1.683), U+V (4.312), U-V (0.946).

Psychosocial Factors: This factor is evaluated with values for V (1.726), U (2.113), U+V (3.839), U-V (0.387).

Insurance: The final results for this factor are V (1.856), U (2.075), U+V (3.931), U-V (0.22).

The results in Table XI offer a quantified understanding of the factors' individual contributions and their combined effects. These metrics provide insights into the central tendency, range, and upper bounds of the factors, allowing for a nuanced interpretation of their significance in the transition process.

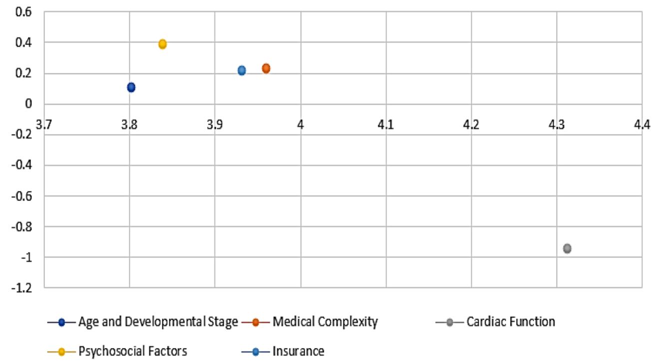

Fig. 1. Cause-Effect Graph.

The above Fig. 1 shows the relationship between five variables: Age and Developmental Stage, Medical Complexity, Psychosocial Factors, Insurance, and Cardiac Function. The x-axis reflects variable prominence, indicating influence levels, while the y-axis denotes their causative or resultant nature. Variables with high x-values and low y-values, like Cardiac Function and Insurance, are primary outcomes strongly influenced by others. Those with high x-values and near-zero y-values, such as Age and Developmental Stage, Medical Complexity, and Psychosocial Factors, act as both causes and effects. Variables with low x-values and near-zero y-values are independent, lacking strong influences. Notably, no variable has both high x and y-values, suggesting a lack of variables solely causing the problem.

V. CONCLUSION

In conclusion, the application of the Fuzzy DEMATEL approach has offered a quantified understanding of critical factors in the transition from pediatric patients with congenital heart disease to adolescence. The numerical values from Table XI underscore the distinct contributions of each factor, revealing noteworthy insights. Age and Developmental Stage, with a combined upper bound and mean value of 3.802, exhibits a significant overall influence with a relatively narrow range (U-V = 0.106). Medical Complexity demonstrates substantial impact (U+V = 3.96) with a moderate range (U-V = 0.233). Cardiac Function emerges as a key determinant (U+V = 4.312) with a broader impact range (U-V = 0.946). Psychosocial Factors and Insurance, with U+V values of 3.839 and 3.931, respectively, demonstrate moderate to substantial influences. These numerical assessments provide a tangible basis for prioritizing interventions and tailoring transition strategies, laying the groundwork for informed clinical and policy decisions in pediatric-to-adolescent transition care for congenital heart disease patients.

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