UNIVERSITI TEKNOLOGI MARA

MATHEMATICS LETTERS
https://sites.google.com/tmsk.uitm.edu.my/mathematicsletters

Evaluating Key Factors Influencing Healhcare Service Quality using the Fuzzy DEMATEL Method

[1]Muhammad Syafiq Ikhwan Mohd Nizam, [2,*]Noratika Nordin & [3] Nur Zafirah Mohd Sidek
[1,2*&3]Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA Shah Alam, 40450, Shah Alam, Selangor.
[1]2023414898@student.uitm.edu.my
[*2] noratikanordin@uitm.edu.my
[3] nurzafirah@uitm.edu.my
*Corresponding author

Received: 11/10/2026 Revised: 21/10/2026 Accepted: 25/10/2026 Published: 31/10/2026

ABSTRACT

Healthcare service quality is influenced by multiple interrelated factors, making it challenging for healthcare administrators to prioritise limited resources effectively. This study aims to identify the key factors influencing healthcare service quality and examine the causal relationships among them. Ten criteria were selected from the literature: service quality, patient safety, staff performance, management, facilities, financial resources, pre-service orientation and training, communication, systems, and equipment. Three experts with more than five years of experience in healthcare counselling or clinical management evaluated the interrelationships among these criteria using a five-point linguistic scale. The responses were converted into triangular fuzzy numbers and analysed using the Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) method. The prominence (D + R) and net relation (D − R) values were calculated to determine the relative importance of each criterion and classify them into cause and effect groups. The results identified management, facilities, financial resources, pre-service orientation and training, systems, and equipment as cause factors, while service quality, patient safety, staff performance, and communication were classified as effect factors. Financial resources emerged as the strongest cause factor, whereas management recorded the highest overall prominence. These findings suggest that healthcare administrators should prioritise resource allocation, management practices, and staff training to improve healthcare service quality. This study also demonstrates the applicability of Fuzzy DEMATEL in analysing interrelated healthcare quality factors and supporting strategic decision-making.

Keywords: Causal relationship, Fuzzy DEMATEL, healthcare service quality, healthcare management, multi-criteria decision making.

INTRODUCTION

Healthcare service quality is an important factor in ensuring effective treatment, patient safety, and patient satisfaction. Patients expect healthcare providers to deliver reliable, efficient, and patient-

centred services. Good service quality also contributes to patients' trust and overall healthcare outcomes (Santana et al., 2021; Ferreira et al., 2023). However, maintaining high-quality healthcare services remains challenging because healthcare providers must address several operational and organisational issues while managing limited resources.

One of the main challenges is that healthcare service quality depends on multiple interconnected factors rather than a single issue. These factors include patient safety, staff performance, management, facilities, financial resources, training, communication, systems, and equipment. For example, inadequate financial resources may limit staff training and equipment availability, while ineffective management may affect resource allocation and daily operations. These challenges can influence the quality of care provided to patients (Bastani et al., 2021; Bhati et al., 2023). Therefore, identifying important factors alone may not be sufficient; understanding how they influence one another is also necessary.

Previous studies have examined healthcare service quality using different approaches, including thematic analysis, structural equation modelling, simulation modelling, and systematic reviews (Huang et al., 2024; Parindra et al., 2024; Prayetno & Mikkael, 2025). Although these studies provide useful insights, the literature reviewed for this study indicates a need to examine the causal relationships among a broader set of healthcare service quality criteria within a single framework. Without understanding these relationships, healthcare administrators may find it difficult to distinguish the underlying causes of service quality problems from factors that are mainly affected by other issues. Consequently, improvement efforts may focus on visible problems without addressing their underlying causes.

The Fuzzy Decision-Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) method offers a systematic approach to addressing this problem. It combines fuzzy set theory with DEMATEL to analyse expert judgements under uncertainty and identify cause-and-effect relationships among interrelated criteria (Abdullah et al., 2023; Akhtar & Asim, 2024). This approach can help determine which factors exert greater influence and which are more strongly influenced by others. Therefore, this study applies Fuzzy DEMATEL to evaluate ten criteria influencing healthcare service quality in Shah Alam. Expert evaluations are used to analyse the relationships among the criteria, classify them into cause and effect groups, and determine their relative importance. The findings are intended to support healthcare administrators in prioritising improvement strategies and allocating resources more effectively.

LITERATURE REVIEW

Healthcare Service Quality

Many studies have examined healthcare service quality from different perspectives. Each study provides useful information but does not give a complete picture of the issue. Bastani et al. (2021) used a thematic analysis approach to find the main themes that matter for improving healthcare care quality. Prayetno and Mikkael (2025) used Structural Equation Modelling to work out how different criteria affect healthcare performance. Huang et al. (2024) looked closely at operational efficiency, using simulation modelling to study healthcare settings directly. Parindra et al. (2024) used a PRISMA based systematic review to identify sustainable improvements that can be made in healthcare health services. Table 2.1 summarises these four studies.

Table 2.1

Summary of Previous Studies on Healthcare Service Quality

Author / Year	Method / Approach	Purpose / Key Contribution
Bastani et al. (2021)	Thematic analysis with inductive approach	Identified the main themes in improving the quality of healthcare care
Prayetno & Mikkael (2025)	Structural Equation Modeling (SEM) using IBM SPSS Amos v26	Analysed how criteria impact other criteria in healthcare performance
Huang et al. (2024)	Simulation modelling	Highlighted operational efficiency in healthcare settings
Parindra et al. (2024)	PRISMA methodology	Achieved sustainable improvements in healthcare health services and patient outcomes

Together, these studies show one clear point. Healthcare service quality is influenced by many organisational and operational factors. It cannot be explained by just one factor alone. Based on the criteria used in these studies, service quality was the only criterion that appeared in every study reviewed. This shows that it is an important part of evaluating healthcare performance. Other criteria that were commonly included were management, facilities, financial resources, communication, equipment, staff performance and patient safety.

Fuzzy Dematel

Fuzzy DEMATEL has been used in many different fields. The studies reviewed here show how flexible the method is when a problem involves many related factors under uncertain conditions. Kuzu (2023) used it to study the risk of anchor loss in maritime transportation. Priyanka et al. (2023) used it to find the human resource problems faced by start up companies. Abdullah et al. (2023) used it for smart manufacturing technologies, and Akhtar and Asim (2024) used it to study enterprise flexibility in the Indian pharmaceutical industry. Singh et al. (2023) applied the method to the barriers of Lean Six Sigma implementation in the healthcare sector. Table 2.2 summarises these applications.

Table 2.2

Summary of Previous Studies Applying Fuzzy DEMATEL

Author / Year	Application	Methodological Contribution	Key Findings / Outcome
Kuzu (2023)	Risk of anchor loss in maritime transportation	Determined factors from literature review, technical reports, and expert views	Captured expert opinions more reliably and reduced ambiguity in weight derivation
Priyanka et al. (2023)	Challenges faced by start up companies	Integrated fuzzy DEMATEL using challenges from literature and expert consultation	Prioritised the most critical factors for effective decision making
Abdullah et al. (2023)	Smart manufacturing technologies	Identified interrelationships and criterion weights	Improved ability to interpret fuzzy information and analyse inter factor

Author / Year	Application	Methodological Contribution	Key Findings / Outcome
			relationships
Akhtar & Asim (2024)	Indian pharmaceutical industry	Developed a cause and effect model of enterprise flexibility dimensions	Determined a cause and effect diagram guiding sustainable improvement
Singh et al. (2023)	Lean Six Sigma barriers in healthcare	Applied fuzzy DEMATEL to expert collected data on implementation barriers	Identified interconnected barriers, improving decision making

Even though these studies cover different fields, they all show that the Fuzzy DEMATEL method is useful for identifying cause and effect relationships and dealing with the uncertainty of expert judgments. Healthcare service quality is also influenced by many connected factors such as patient safety, staff performance, management, facilities, communication and financial resources. Because of this, the Fuzzy DEMATEL method is suitable for this study.

These factors appeared frequently in the studies shown in Table 2.1. Based on the literature review, the ten most common criteria were selected for the Fuzzy DEMATEL analysis in this study. These are service quality (C1), patient safety (C2), staff performance (C3), management (C4), facilities (C5), financial resources (C6), pre-service orientation and training (C7), communication (C8), system (C9) and equipment (C10). Table 2.3 explains the definition of each criterion used in this study.

Table 2.3

Definition of Criteria Used in This Study

Code	Criteria	Meaning
C1	Service Quality	The ability of a healthcare to provide healthcare services that meet or exceed patients' expectations in terms of reliability, responsiveness, and effectiveness.
C2	Patient Safety	The prevention of medical errors, injuries, and risks that may harm patients during healthcare delivery.
C3	Staff Performance	The effectiveness, competence, productivity, and professionalism of healthcare workers in providing medical services.
C4	Management	The planning, organising, directing, and controlling of healthcare resources and operations to achieve healthcare objectives efficiently.
C5	Facilities	The physical infrastructure, environment, and support amenities available in a healthcare to facilitate healthcare services.
C6	Financial Resources	The availability and management of funds required to support healthcare operations, equipment, staffing, and service improvements.
C7	Pre-Service Orientation & Training	Educational and training programmes provided to healthcare staff before and during employment to improve knowledge, skills, and competencies.
C8	Communication	The exchange of information among healthcare professionals, patients, and stakeholders to ensure effective healthcare delivery.
C9	System	The procedures, policies, information systems, and operational

Code	Criteria	Meaning
		processes that support healthcare management and healthcare services.
C10	Equipment	Medical devices, technologies, and tools used by healthcare professionals to diagnose, monitor, and treat patients.

Factors Influencing Healthcare Service Quality

Besides the studies discussed earlier, other researchers have also tried to identify the organisational factors that influence healthcare service quality. In a systematic review, the researchers grouped the dimensions of healthcare service quality into areas such as healthcare management and administration, personnel characteristics and patient-related factors. They found that service quality problems are usually not caused by a single factor. Instead, they result from the interaction between resources, management practices and staff capability. This is similar to the ten criteria used in this study, as most of them fall under the same organisational and provider-related categories (Darzi et al. 2023), Bhati et al. (2023) study focused more on how healthcare administration affects patient outcomes. It found that effective administration, including clear management structures, proper financial planning and good communication, was associated with better patient safety and higher patient satisfaction. When compared with the studies discussed in Section 2.3, both areas of research show a similar pattern even though they were not directly compared. The DEMATEL studies show that multi-criteria methods can identify the cause and effect relationships between different criteria. At the same time, the studies on healthcare administration suggest that management and financial resources are some of the main factors that influence healthcare service quality.

RESEARCH METHODOLOGY

Definition Of Terms And Concepts

Fuzzy set. A fuzzy set S is defined by a set of ordered pairs $S = \{x, \mu S(x) \mid x \in S\}$, $\mu S(x) \in [0,1]$, where $\mu S(x)$ is a membership function specifying the grade or degree to which an element x belongs to the fuzzy set S (Zadeh, 1965).

Fuzzy number. A fuzzy number $\tilde{S}$ is a fuzzy subset of the universe of discourse X that is both convex and normal. It is said to be positive if its membership function $\mu S(x) = 0$ for all $x < 0$.

Triangular fuzzy number (TFN). A triangular fuzzy number is a fuzzy number represented by a triplet $\tilde{S} = (l, m, u)$, where $l \le m \le u$, and whose membership function is:

$$\mu\tilde{S}(x) = 0 \text{ for } x < l;\ (x-l)/(m-l) \text{ for } l \le x \le m;\ (u-x)/(u-m) \text{ for } m \le x \le u;\ 0 \text{ for } x > u$$

Fuzzy arithmetic. For two positive triangular fuzzy numbers $\tilde{S}_1 = (l_1, m_1, u_1)$ and $\tilde{S}_2 = (l_2, m_2, u_2)$, the operations used in this study are (Chou et al., 2012):

$$\tilde{S}_1 \oplus \tilde{S}_2 = (l_1+l_2, m_1+m_2, u_1+u_2) \qquad \tilde{S}_1 \ominus \tilde{S}_2 = (l_1-u_2, m_1-m_2, u_1-l_2)$$
$$\tilde{S}_1 \otimes \tilde{S}_2 = (l_1l_2, m_1m_2, u_1u_2) \qquad \tilde{S}_1 \oslash \tilde{S}_2 = (l_1/u_2, m_1/m_2, u_1/l_2)$$

Linguistic variable. A linguistic variable is characterised by (X, Q, U, M), where X is the name of the variable, Q is the set of linguistic values X can take, U is the physical domain over which X takes its crisp values, and M is a semantic rule relating each linguistic value to a fuzzy set in U (Wang, 1997).

Defuzzification. Defuzzification is the process of converting a fuzzy number into a single crisp value, often referred to as the best non-fuzzy performance (BNP) value, obtained here from the centre-of-area of each triangular fuzzy number (Baykasoğlu et al., 2011).

Decision-Making Trial and Evaluation Laboratory (DEMATEL). DEMATEL is a structural modelling method used to identify cause-and-effect relationships among a set of factors. It converts pairwise comparisons of the factors into a directed graph (digraph) that separates the factors into a cause group and an effect group (Chang et al., 2011).

Data Collection

Ten criteria were shortlisted from the literature review in Chapter 2 (Table 2.3): service quality (C1), patient safety (C2), staff performance (C3), management (C4), facilities (C5), financial resources (C6), pre-service orientation and training (C7), communication (C8), system (C9), and equipment (C10). A structured questionnaire (Appendix A) was then designed around these ten criteria and distributed to three experts, each with at least five years of experience in healthcare counselling or clinical management.

A panel of three experts is acceptable for a Fuzzy DEMATEL study. Unlike survey-based research, which usually requires a large sample size, Fuzzy DEMATEL relies on the knowledge and experience of experts. Their judgments are used for the analysis rather than for statistical purposes. Most published Fuzzy DEMATEL studies, including the work by Wu and Lee (2007) and the more recent study by Çevik Aka (2023), use expert panels of around three to eight people. This is because the method focuses more on the knowledge and experience of the experts than on having a large number of respondents. A recent bibliometric review of more than 3,500 DEMATEL studies shows that the method is still widely used and remains a reliable approach for research (Sorooshian et al., 2023). All three experts in this study had more than five years of experience in healthcare counselling or clinical management. Their experience was given priority over the number of experts to ensure that the judgments were based on practical knowledge of healthcare service quality.

Each expert was asked to rate, for every ordered pair of criteria (Ci, Cj), the degree to which Ci influences Cj, using the five-point linguistic scale in Table 3.1. A criterion was never compared against itself, so the diagonal of every expert's response matrix was left at zero.

Table 3.1

Linguistic Terms and Corresponding Triangular Fuzzy Numbers

Linguistic Term	Influence Level	Fuzzy Value (l, m, u)
No influence (No)	0	(0.0, 0.0, 2.5)
Very Low Influence (VL)	1	(0.0, 2.5, 5.0)
Low Influence (L)	2	(2.5, 5.0, 7.5)

Linguistic Term	Influence Level	Fuzzy Value (l, m, u)
High Influence (H)	3	(5.0, 7.5, 10.0)
Very High Influence (VH)	4	(7.5, 10.0, 10.0)

The Fuzzy Dematel Method

Once the expert responses had been collected, they were processed through the nine steps Fuzzy DEMATEL procedure below, following the general structure set out in the foundational Fuzzy DEMATEL literature (Wu & Lee, 2007; Baykasoğlu et al., 2013). All calculations were carried out using Microsoft Excel. Each step of the process, from the direct relation matrix to the final criteria weights, was completed using linked spreadsheet formulas. This made it possible to trace the results back to the original questionnaire responses whenever needed.

STEP 1: CONSTRUCT THE DIRECT-RELATION FUZZY MATRIX, $\tilde{Z}$

Based on the linguistic scores collected from the three experts, a direct-relation fuzzy matrix $\tilde{Z}$ was constructed for each expert, where $\tilde{Z}$ is an n × n matrix (n = 10) whose elements $\tilde{Z}ij = (zij,l, zij,m, zij,u)$ are triangular fuzzy numbers indicating the degree to which criterion Ci influences criterion Cj. The three experts' matrices were then averaged element-by-element to obtain a single aggregated direct-relation fuzzy matrix.

STEP 2: CONSTRUCT THE NORMALIZED DIRECT-RELATION FUZZY MATRIX, $\tilde{X}$

The normalized direct-relation fuzzy matrix $\tilde{X}$ was obtained by dividing every element of the aggregated matrix $\tilde{Z}$ by the largest row-sum found across its l, m, and u components separately, ensuring every value fell between 0 and 1:

$$\tilde{X}ij = \tilde{Z}ij / \tilde{M}, \quad \text{where } \tilde{M} = (ml, mm, mu) \text{ and } ms = \max_i (\Sigma_j \tilde{Z}ij,s), \ s = l, m, u$$

STEP 3: CONSTRUCT THE TOTAL-RELATION FUZZY MATRIX, $\tilde{T}$

The total-relation fuzzy matrix $\tilde{T}$ captures both the direct and indirect influence of every criterion on every other criterion, obtained from:

$$\tilde{T} = \lim(w\to\infty) (\tilde{X} + \tilde{X}^2 + \ldots + \tilde{X}^w) = \tilde{X} (I - \tilde{X})^{-1}$$

In practice, this was computed by treating the l, m, and u components of $\tilde{X}$ as three separate crisp matrices Xl, Xm, and Xu, and applying the identity above to each independently:

$$Tl = Xl (I - Xl)^{-1}, \quad Tm = Xm (I - Xm)^{-1}, \quad Tu = Xu (I - Xu)^{-1}$$

STEPS 4 & 5: ROW AND COLUMN SUMS, AND DEFUZZIFICATION

For each criterion i, the row sum $\tilde{D}i$ of the total-relation matrix represents the total influence criterion i dispatches to all other criteria, while the column sum $\tilde{R}i$ represents the total influence criterion i receives:

$$\tilde{D}i = \Sigma_j \tilde{T}ij, \quad \tilde{R}i = \Sigma_j \tilde{T}ji$$

These fuzzy row and column sums were then defuzzified using the standard weighted-average formula:

$$Didef = \tfrac{1}{4}(di,l + 2di,m + di,u), \quad Ridef = \tfrac{1}{4}(ri,l + 2ri,m + ri,u)$$

STEPS 6 & 7: THRESHOLD VALUE AND THE CAUSAL DIAGRAM

Not every relationship in the total-relation matrix is strong enough to be meaningful. To filter out weak relationships, the total-relation matrix was first defuzzified element-by-element, $Tave,ij = (tij,l + tij,m + tij,u) / 3$, and then normalized by dividing every element by the largest value in Tave: $Nij = Tave,ij / \max(Tave,ij)$. The threshold value α was then calculated as the average of all elements in N:

$$\alpha = (\Sigma_i \Sigma_j Nij) / N, \quad \text{where N is the total number of elements in the matrix}$$

Any relationship whose normalized value fell below α was excluded from the causal diagram, as its influence was considered too weak to be meaningful. Each criterion was then plotted on a causal diagram with prominence (Didef + Ridef) on the horizontal axis and relation (Didef − Ridef) on the vertical axis. A criterion with Didef − Ridef greater than zero dispatches more influence than it receives and is classified under the cause group; a criterion with Didef − Ridef less than zero receives more influence than it dispatches and is classified under the effect group (Chang et al., 2011).

STEPS 8 & 9: CRITERIA WEIGHT AND NORMALIZATION

The weight of each criterion was calculated as the Euclidean distance of the criterion from the origin of the causal diagram:

$$\omega i = \sqrt{[(Didef + Ridef)^2 + (Didef - Ridef)^2]}$$

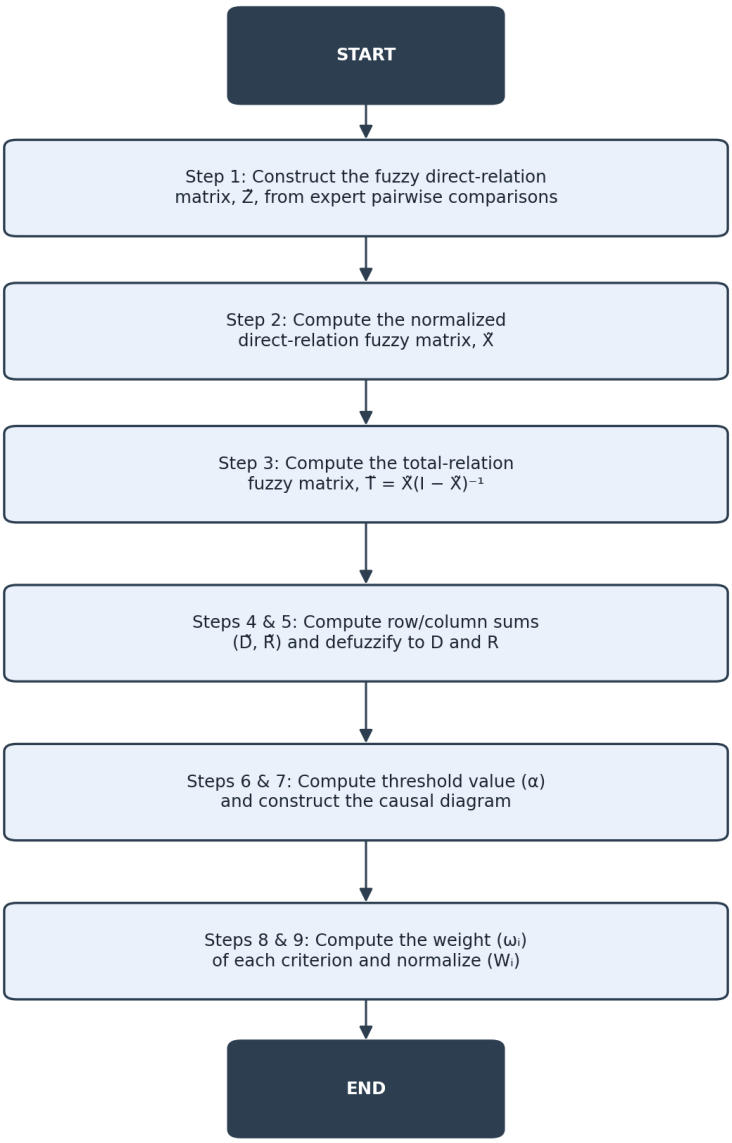
This weight was then normalized so that all criteria weights summed to 1, giving the final relative importance Wi of each criterion:

$$Wi = \omega i / \Sigma_i \omega i$$

Figure 3.1 summarises the nine-step procedure described above.

Figure 3.1

The Procedure of the Fuzzy DEMATEL Method



IMPLEMENTATION

Direct-Relation Fuzzy Matrix

The raw linguistic scores collected from the three experts (Appendix B) were converted into triangular fuzzy numbers using the scale in Table 3.1, then averaged element by element into a single aggregated direct-relation fuzzy matrix $\tilde{Z}$ (Step 1, Section 3.3). Table 4.1 presents the medium (m) part of this matrix. The full l, m, and u parts are given in Appendix D.

Table 4.1

Direct-Relation Fuzzy Matrix (Medium Component)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	0.00	9.17	10.00	9.17	9.17	8.33	9.17	10.00	9.17	9.17
C2	9.17	0.00	9.17	9.17	9.17	9.17	9.17	9.17	9.17	8.33
C3	10.00	10.00	0.00	10.00	10.00	9.17	9.17	10.00	8.33	9.17
C4	10.00	10.00	10.00	0.00	10.00	10.00	10.00	10.00	10.00	10.00
C5	10.00	10.00	10.00	10.00	0.00	10.00	10.00	10.00	10.00	10.00
C6	9.17	9.17	9.17	9.17	9.17	0.00	9.17	9.17	9.17	9.17
C7	10.00	10.00	10.00	9.17	9.17	9.17	0.00	10.00	9.17	9.17
C8	10.00	10.00	10.00	10.00	9.17	9.17	10.00	0.00	8.33	9.17
C9	10.00	9.17	9.17	10.00	9.17	9.17	9.17	9.17	0.00	9.17
C10	10.00	10.00	9.17	9.17	10.00	9.17	9.17	9.17	9.17	0.00

Normalized Direct-Relation Fuzzy Matrix

The aggregated matrix in Table 4.1 was normalised by dividing every element by the largest row sum found across the l, m, and u parts (Step 2, Section 3.3). Table 4.2 presents the medium (m) part of the resulting normalised matrix $\tilde{X}$. The full l, m, and u parts are given in Appendix E.

Table 4.2

Normalized Direct-Relation Fuzzy Matrix (Medium Component)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	0.000	0.102	0.111	0.102	0.102	0.093	0.102	0.111	0.102	0.102
C2	0.102	0.000	0.102	0.102	0.102	0.102	0.102	0.102	0.102	0.093
C3	0.111	0.111	0.000	0.111	0.111	0.102	0.102	0.111	0.093	0.102
C4	0.111	0.111	0.111	0.000	0.111	0.111	0.111	0.111	0.111	0.111

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C5	0.111	0.111	0.111	0.111	0.000	0.111	0.111	0.111	0.111	0.111
C6	0.102	0.102	0.102	0.102	0.102	0.000	0.102	0.102	0.102	0.102
C7	0.111	0.111	0.111	0.102	0.102	0.102	0.000	0.111	0.102	0.102
C8	0.111	0.111	0.111	0.111	0.102	0.102	0.111	0.000	0.093	0.102
C9	0.111	0.102	0.102	0.111	0.102	0.102	0.102	0.102	0.000	0.102
C10	0.111	0.111	0.102	0.102	0.111	0.102	0.102	0.102	0.102	0.000

Total-Relation Fuzzy Matrix

The total-relation fuzzy matrix $\tilde{T} = \tilde{X}(I - \tilde{X})^{-1}$ was then calculated for each of the three fuzzy parts (Step 3, Section 3.3). Table 4.3 presents the medium (m) part of this matrix. The full l, m, and u parts, together with a note on how the calculation was verified, are given in Appendix F.

Table 4.3

Total-Relation Fuzzy Matrix (Medium Component)

Criteria	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
C1	1.71	1.78	1.78	1.75	1.72	1.72	1.72	1.78	1.69	1.71
C2	1.81	1.71	1.79	1.77	1.74	1.74	1.74	1.79	1.71	1.72
C3	1.90	1.89	1.77	1.86	1.82	1.82	1.82	1.87	1.78	1.80
C4	1.98	1.96	1.95	1.83	1.90	1.90	1.90	1.95	1.87	1.88
C5	1.98	1.96	1.95	1.93	1.80	1.90	1.90	1.95	1.87	1.88
C6	1.83	1.82	1.80	1.79	1.76	1.66	1.76	1.80	1.73	1.74
C7	1.92	1.90	1.89	1.86	1.83	1.84	1.74	1.89	1.80	1.81
C8	1.92	1.90	1.89	1.87	1.83	1.83	1.84	1.79	1.80	1.82
C9	1.87	1.85	1.83	1.82	1.79	1.79	1.79	1.83	1.66	1.77
C10	1.88	1.87	1.85	1.83	1.81	1.80	1.80	1.85	1.77	1.69

Sum Of Row And Sum Of Column Of The Total-Relation Matrix

The sum of each row, $\tilde{D}i$, and the sum of each column, $\tilde{R}i$, of the total-relation matrix were then calculated (Step 4, Section 3.3). Table 4.4 presents these fuzzy row and column sums for each criterion, shown as (l, m, u) triplets.

Table 4.4

Sum of Row and Sum of Column of Total-Relation Matrix

Code	D̃i (l, m, u)	R̃i (l, m, u)
C1	(12.53, 17.35, 1099.75)	(13.98, 18.80, 1109.00)
C2	(12.69, 17.51, 1109.00)	(13.82, 18.64, 1109.00)
C3	(13.51, 18.32, 1109.00)	(13.67, 18.48, 1109.00)
C4	(14.30, 19.12, 1109.00)	(13.50, 18.32, 1109.00)
C5	(14.30, 19.12, 1109.00)	(13.17, 17.99, 1109.00)
C6	(12.85, 17.67, 1109.00)	(13.16, 17.99, 1099.75)
C7	(13.64, 18.47, 1109.00)	(13.17, 17.99, 1109.00)
C8	(13.66, 18.48, 1109.00)	(13.67, 18.48, 1109.00)
C9	(13.18, 18.00, 1109.00)	(12.84, 17.66, 1109.00)
C10	(13.33, 18.15, 1109.00)	(13.01, 17.83, 1109.00)

Defuzzification Of D And R

The fuzzy row and column sums in Table 4.4 were defuzzified using the weighted average formula in Step 5, Section 3.3, giving a single crisp value Didef and Ridef for each criterion. Table 4.5 presents these defuzzified values.

Table 4.5

Defuzzification of D and R

Code	Criteria	Didef	Ridef
C1	Service Quality	286.7442	290.1421
C2	Patient Safety	289.1784	290.0248
C3	Staff Performance	289.7888	289.9085
C4	Management	290.3835	289.7821
C5	Facilities	290.3835	289.5373
C6	Financial Resources	289.2991	287.2224
C7	Pre-Service Orientation & Training	289.8928	289.5384
C8	Communication	289.9028	289.9085
C9	System	289.5417	289.2923
C10	Equipment	289.6580	289.4164

Threshold Value

Following Steps 6 and 7, Section 3.3, the total-relation matrix was defuzzified element by element and normalised by its largest value, giving the matrix N. The threshold value was then calculated as the average of every element in N, giving $\alpha = 0.9956$. Any relationship in N below this value was treated as too weak to be shown on the causal diagram in Chapter 5. The full normalised, defuzzified matrix used to calculate this threshold is given in Appendix F.

Prominence, Relation, And Weight Of The Criteria

Using the defuzzified values in Table 4.5, the prominence (D + R) and relation (D − R) of each criterion were calculated, and each criterion was placed into the cause group or the effect group depending on the sign of its relation value (Step 7, Section 3.3). The weight and normalised weight of each criterion were then calculated following Steps 8 and 9, Section 3.3. Table 4.6 presents the complete result of this implementation.

Table 4.6

Prominence, Relation, Group, and Weight of the Criteria

Code	Criteria	D + R	D − R	Group	Weight (ω_i)	Normalized Weight (W_i)
C1	Service Quality	576.8862	−3.3979	Effect	576.8962	0.0996
C2	Patient Safety	579.2032	−0.8464	Effect	579.2038	0.1000
C3	Staff Performance	579.6973	−0.1197	Effect	579.6973	0.1001
C4	Management	580.1657	+0.6014	Cause	580.1660	0.1002
C5	Facilities	579.9208	+0.8463	Cause	579.9214	0.1002
C6	Financial Resources	576.5216	+2.0767	Cause	576.5253	0.0996
C7	Pre-Service Orientation & Training	579.4312	+0.3544	Cause	579.4313	0.1001
C8	Communication	579.8113	−0.0057	Effect	579.8113	0.1001
C9	System	578.8340	+0.2494	Cause	578.8341	0.1000
C10	Equipment	579.0744	+0.2415	Cause	579.0745	0.1000

These results are carried forward into Chapter 5, where the causal diagram is plotted and the findings are discussed in detail.

5RESULT AND DISCUSSION

Numerical Stability Of The Total-Relation Matrix

One feature of the data worth noting is that the experts rated most pairs of criteria close to the top of the scale. Because of this, the normalised matrix in Table 4.2 had row sums very close to 1 for nine of the ten criteria. This makes the matrix $(I - \tilde{X})$ close to singular. This is a known feature of DEMATEL

analyses when expert opinions are strongly similar and cluster near the top of the scale. To avoid the numerical problems this can cause, the total relation matrix in Table 4.3 was computed using exact fraction based arithmetic instead of normal decimal calculation, and the results were checked again using two separate computer methods before being accepted. Both methods produced the same results up to at least six decimal places. This gives confidence that the total relation matrix is reliable, even though the system is close to being singular.

Threshold Value And Significant Relationships

As calculated in Section 4.6, the threshold value was $\alpha = 0.9956$. After applying this threshold to the normalised and defuzzified total relation matrix, 71 out of the 90 possible off-diagonal relationships, or about 78.9%, were found to be significant. This means that most of the criteria in this study have a meaningful influence on each other. Only a few pairs of criteria showed no significant relationship. This is consistent with the findings from the literature review in Chapter 2, where the same criteria appeared repeatedly in different studies on healthcare service quality.

Prominence, Relation, And Cause-Effect Grouping

Table 4.6 in Chapter 4 presents the prominence ($D + R$) and relation ($D - R$) values for each criterion, together with their cause or effect group. Six of the ten criteria, namely management, facilities, financial resources, pre-service orientation and training, system and equipment, were identified as cause factors. This means they have a greater influence on the other criteria than the influence they receive. The remaining four criteria, service quality, patient safety, staff performance and communication, were identified as effect factors. This means they are influenced more by the other criteria than they influence the system themselves.

Financial resources had the highest positive relation value ($D - R = +2.08$). This shows that it is the strongest cause factor among the ten criteria, even though its prominence value was relatively low. This is a common finding in DEMATEL studies. A factor does not have to be the most central in the system to have a strong influence. It only needs to influence other factors more than it is influenced by them. Facilities and management followed with relation values of +0.85 and +0.60. These findings suggest that financial resources and organisational management play an important role in influencing the more visible aspects of healthcare service quality.

On the effect side, service quality had the lowest relation value ($D - R = -3.40$). This shows that it is the strongest effect factor among the ten criteria. The finding suggests that service quality is mainly influenced by the other nine criteria rather than being improved directly. Patient safety (−0.85), staff performance (−0.12) and communication (−0.01) were also identified as effect factors. However, their relation values were much closer to zero than service quality. This means that staff performance and communication are close to the boundary between the cause and effect groups. Small changes in expert judgments could place them in either group.

Management had the highest prominence value ($D + R = 580.17$). This means it has the strongest overall interaction with the other criteria in the system. Since it was also identified as a cause factor, management can be considered one of the main drivers of healthcare service quality. This suggests that healthcare administrators should give priority to improving management because it can influence many other criteria in the system.

Figure 5.1

Causal Diagram of Factors Influencing Healthcare Service Quality

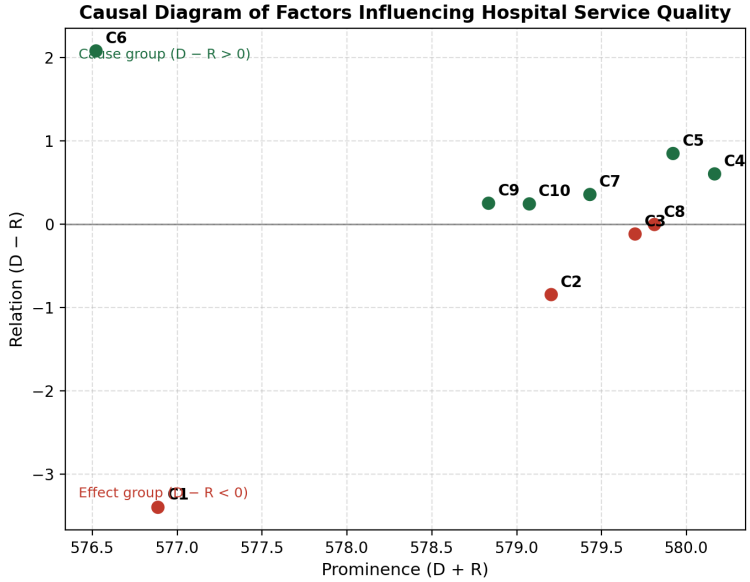


Figure 5.1 plots all ten criteria by prominence (horizontal axis) and relation (vertical axis). The six cause factors sit above the zero line, and the four effect factors sit below it. The figure also shows that the spread along the vertical axis is fairly narrow for most criteria, other than service quality and financial resources. Most points cluster close to the horizontal line. This shows the strong, near uniform influence ratings the experts gave across most pairs of criteria.

Criteria Weights

Table 4.6 in Chapter 4 also shows the weight and normalised weight of each criterion, calculated as the Euclidean distance of each criterion from the origin of the causal diagram. Because prominence is the main part of the weight calculation, and prominence values are close together, the normalised weights are all close to the 0.10 mark that ten equally weighted criteria would give. Management and facilities rank slightly above the rest, at 0.1002 each, while service quality and financial resources rank slightly below, at 0.0996 each. Read alone, the weight ranking might suggest that all ten criteria matter almost equally. Read together with the cause and effect grouping in Section 5.3, a clearer picture appears. The criteria do not have the same level of influence on the system, even though they are similarly important within it.

Discussion Of Findings

Overall, the results highlight three main points. The first finding is that management has a strong influence on healthcare service quality. In this study, management had the highest prominence value and was identified as a cause factor. This is consistent with the findings discussed in Chapter 2. The second finding is that financial resources were the strongest cause factor, with the highest relation value in the data set. This suggests that financial resources are more than just one of many factors. They influence other important areas such as training, equipment and staffing. When a healthcare has limited financial resources, it can also affect many other aspects of healthcare service quality.

The third and the most important finding is that service quality was identified as the strongest effect factor in the system. This is important because it suggests that improving service quality directly may not be very effective if the main causes are not addressed first. Instead, healthcares should focus on improving areas such as management, facilities, financial resources, staff training and system design. By improving these factors, service quality, patient safety, staff performance and communication are also expected to improve without requiring separate actions.

It is also worth noting a limitation found during the analysis. Because the three experts in this study rated most pairs of criteria close to the top of the scale, the total relation matrix ended up close to numerically singular. The differences between many of the $D - R$ values are therefore small. Several criteria differ from their neighbours by only a few hundredths, on a scale where prominence values run into the hundreds. The ranking and grouping reported here were checked twice using exact arithmetic and are numerically sound. However, a wider range of expert opinion, or a larger expert panel, would likely produce a causal diagram with clearer separation between criteria. This is a good direction for future work.

CONCLUSION AND RECOMMENDATION

Conclusion

This study aimed to identify the key factors influencing healthcare service quality and to understand how these factors influence one another, using the Fuzzy DEMATEL method to work through the uncertainty that comes with relying on expert judgment. All three objectives set out in Chapter 1 were achieved. Ten criteria were identified through a systematic literature review. Expert evaluations on the relationships among these criteria were collected through a structured questionnaire completed by three experienced healthcare professionals. The resulting data were analysed using Fuzzy DEMATEL to find the causal structure linking the ten criteria.

The analysis found that management, facilities, financial resources, pre-service orientation and training, system, and equipment act as cause factors within the system. Service quality, patient safety, staff performance, and communication act as effect factors. Financial resources was the strongest cause factor, and management had the greatest overall prominence, making it the criterion most central to the system as a whole. Service quality itself was found to be the strongest effect factor of all ten criteria. This suggests it is best treated as an outcome shaped by the other nine criteria, rather than a target for direct action.

Overall, these findings provide a clear answer to the research question of this study. If a healthcare wants to improve its service quality, it should focus more on areas such as management, facilities, financial resources, staff training and system design. The results suggest that improving these factors is likely to have a greater impact than focusing only on service quality, patient safety or communication.

Limitations Of The Study

This study has several limitations. First, the evaluation was based on the judgments of only three experts. Although this is sufficient for a Fuzzy DEMATEL analysis, a larger group of experts could provide more reliable results. Second, the experts gave high ratings for most pairs of criteria, which resulted in only small differences between some of the causal relationships. A larger and more diverse group of experts may produce a clearer causal diagram. Finally, since this study only focused on

Healthcare in Shah Alam, the findings may not apply directly to healthcares with different resources, regulations, or patient groups.

Recommendations For Future Research

Future studies can improve this research in several ways. One suggestion is to repeat the analysis with a larger group of experts or experts from different locations to see if the same cause and effect relationships are found. It would also be useful to combine the Fuzzy DEMATEL method with other techniques such as the Analytic Network Process (ANP) or Fuzzy TOPSIS. This would help identify the main cause factors and also rank the best improvement strategies. Finally, this study only focused on identifying the relationships between the criteria. Future research could examine whether improving the identified cause factors, such as financial resources or management training, leads to better service quality and patient safety over time.

ACKNOWLEDGEMENT

The authors acknowledge support from the Faculty of Computer and Mathematical Sciences, Universiti Teknologi MARA.

Conflict of Interest
The authors have no conflicts of interest to declare.

Non-funded
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

REFERENCES

Abdullah, F. M., Al-Ahmari, A. M., & Anwar, S. (2023). An integrated Fuzzy DEMATEL and Fuzzy TOPSIS method for analyzing smart manufacturing technologies. *Processes*, *11*(3), 906. https://doi.org/10.3390/pr11030906

Akhtar, M., & Asim, M. (2024). Fuzzy causal model of enterprise flexibility dimensions using Fermatean Fuzzy DEMATEL: A case study of Indian pharmaceutical industry. *Benchmarking: An International Journal*, *32*(4), 1338–1359. https://doi.org/10.1108/bij-07-2023-0462

Bastani, P., Mohammadpour, M., Bahmaei, J., Ravangard, R., & Mehralian, G. (2021). Healthcare management by health services management graduates: The change paradigm in Iran. *Heliyon*, *7*(11), Article e08414. https://doi.org/10.1016/j.heliyon.2021.e08414

Baykasoğlu, A., Göçken, T., & Kaplanoğlu, V. (2011). A practical approach to prioritize project activities through fuzzy ranking. *Cybernetics and Systems: An International Journal*, *42*(3), 165–179.

Baykasoğlu, A., Kaplanoğlu, V., Durmuşoğlu, Z. D., & Şahin, C. (2013). Integrating fuzzy DEMATEL and fuzzy hierarchical TOPSIS methods for truck selection. *Expert Systems with Applications*, *40*(3), 899–907. https://doi.org/10.1016/j.eswa.2012.05.046

Bhati, D., Deogade, M. S., & Kanyal, D. (2023). Improving patient outcomes through effective healthcare administration: A comprehensive review. *Cureus*, *15*(10), Article e47731.

https://doi.org/10.7759/cureus.47731

Chang, B., Chang, C.-W., & Wu, C.-H. (2011). Fuzzy DEMATEL method for developing supplier selection criteria. *Expert Systems with Applications*, *38*(3), 1850–1858. https://doi.org/10.1016/j.eswa.2010.07.114

Chen, L., Chen, C., Loverio, J. P., Wang, M., Lee, L., & Hou, Y. (2023). Examining soft and hard attributes of health care service quality and their impacts on patient satisfaction and loyalty. *Quality Management in Health Care*, *33*(3), 176–191. https://doi.org/10.1097/qmh.0000000000000420

Chou, Y.-C., Sun, C.-C., & Yen, H.-Y. (2012). Evaluating the criteria for human resource for science and technology (HRST) based on an integrated fuzzy AHP and fuzzy DEMATEL approach. *Applied Soft Computing*, *12*(1), 64–71. https://doi.org/10.1016/j.asoc.2011.08.058

Darzi, M. A., Islam, S. B., Khursheed, S. O., & Bhat, S. A. (2023). Service quality in the healthcare sector: A systematic review and meta-analysis. *LBS Journal of Management & Research*, *21*(1), 13–29. https://doi.org/10.1108/LBSJMR-06-2022-0025

De Siqueira Correa, E., Satyro, W. C., Da Silva, L. F., Martens, M. L., & Contador, J. C. (2023). Healthcare 4.0 implementation: Opportunities and challenges in the healthcare sector. *Peer Review*, *5*(15), 163–182. https://doi.org/10.53660/749.prw1933

Endalamaw, A., Khatri, R. B., Erku, D., Nigatu, F., Zewdie, A., Wolka, E., & Assefa, Y. (2023). Successes and challenges towards improving quality of primary health care services: A scoping review. *BMC Health Services Research*, *23*(1), Article 893. https://doi.org/10.1186/s12913-023-09917-3

Ferreira, D. C., Vieira, I., Pedro, M. I., Caldas, P., & Varela, M. (2023). Patient satisfaction with healthcare services and the techniques used for its assessment: A systematic literature review and a bibliometric analysis. *Healthcare*, *11*(5), Article 639. https://doi.org/10.3390/healthcare11050639

Hannawa, A. F., Wu, A. W., Kolyada, A., Potemkina, A., & Donaldson, L. J. (2021). The aspects of healthcare quality that are important to health professionals and patients: A qualitative study. *Patient Education and Counseling*, *105*(6), 1561–1570. https://doi.org/10.1016/j.pec.2021.10.016

Huang, S., Weng, S., Chiou, S., Nguyen, T., Chen, C., Liu, S., & Tsai, Y. (2024). A study on decision-making for improving service efficiency in healthcares. *Healthcare*, *12*(3), Article 405. https://doi.org/10.3390/healthcare12030405

Kuzu, A. C. (2023). Application of fuzzy DEMATEL approach in maritime transportation: A risk analysis of anchor loss. *Ocean Engineering*, *273*, Article 113786. https://doi.org/10.1016/j.oceaneng.2023.113786

Parindra, I. K., Menap, M., & Khalik, L. A. (2024). Optimization of healthcare health services: Insights from recent literature. *Bioscientist: Jurnal Ilmiah Biologi*, *12*(2), 1636. https://doi.org/10.33394/bioscientist.v12i2.12467

Phelan, H., Yates, V., & Lillie, E. (2022). Challenges in healthcare delivery in low- and middle-income countries. *Anaesthesia & Intensive Care Medicine*, *23*(8), 501–504. https://doi.org/10.1016/j.mpaic.2022.05.004

Prayetno, S., & Mikkael, R. H. (2025). Strategies to improve healthcare implementation of management

functions that influence service behavior. *Annals of Human Resource Management Research*, *5*(1), 61–75. https://doi.org/10.35912/ahrmr.v5i1.2790

Priyanka, R., Ravindran, K., Sankaranarayanan, B., & Ali, S. M. (2023). A fuzzy DEMATEL decision modeling framework for identifying key human resources challenges in start-up companies: Implications for sustainable development. *Decision Analytics Journal*, *6*, Article 100192. https://doi.org/10.1016/j.dajour.2023.100192

Santana, I. R., Mason, A., Gutacker, N., Kasteridis, P., Santos, R., & Rice, N. (2021). Need, demand, supply in health care: Working definitions, and their implications for defining access. *Health Economics, Policy and Law*, *18*(1), 1–13. https://doi.org/10.1017/s1744133121000293

Singh, M., Rathi, R., Jaiswal, A., Manishbhai, S. D., Gupta, S. S., & Dewangan, A. (2023). Empirical analysis of Lean Six Sigma implementation barriers in healthcare sector using fuzzy DEMATEL approach: An Indian perspective. *The TQM Journal*, *35*(8), 2367–2386. https://doi.org/10.1108/TQM-05-2022-0152

Wang, L.-X. (1997). *A course in fuzzy systems and control*. Prentice-Hall.

Wu, W. W., & Lee, Y. T. (2007). Developing global managers' competencies using the fuzzy DEMATEL method. *Expert Systems with Applications*, *32*(2), 499–507. https://doi.org/10.1016/j.eswa.2005.12.005

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control*, *8*(3), 338–353. https://doi.org/10.1016/S0019-9958(65)90241-X

Çevik Aka, D. (2023). Fuzzy trapezoidal DEMATEL method for criteria weights in supplier selection: A case study of ice cream producer. InTraders International Trade Academic Journal, 6(2), 97–118. https://doi.org/10.55065/intraders.1365612

Sorooshian, S., Jamali, S. M., & Ale Ebrahim, N. (2023). Performance of the decision-making trial and evaluation laboratory. AIMS Mathematics, 8(3), 7490–7514. https://doi.org/10.3934/math.2023376

This is an open access article under the CC BY-SA license (https://creativecommons.org/licenses/by-sa/4.0/).