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Infection Management in Hospitals Using a Two-Stage Fuzzy Decision-Making Approach

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Abstract: Effective infection management is important for health systems. However, many factors influence infection management. This study aims to determine the most suitable strategies for effective infection management. Factors affecting infection management were determined based on the literature. The Criteria Importance Assessment (CIMAS) method is used for weighting the criteria, while Ranking of Alternatives through Functional mapping of criterion Subintervals into a single Interval (RAFSI) method is used to analyze the most effective alternative. Fuzzy numbers are used to minimize uncertainty during the analysis. Expert selection is based on Z-score weighting. The results of the analysis showed that the most important factors affecting infection management are compliance with patient safety ($w = 0.363$). The results of the alternative analysis show that the most effective strategy is hygiene and handwashing training ($w = 0.826$). In this regard, hospital administrators should ensure that hand hygiene, isolation, and sterilization protocols are implemented within the framework of quality standards. Politicians should establish an audit mechanism for infection management and invest in health infrastructure. The healthcare delivery process is important in terms of sustainability and is mostly provided in hospitals. Digital systems are recommended for monitoring hand hygiene and sterilization. One of the important original contributions of this study is the introduction of a set of factors affecting infection management into the literature. Furthermore, it is the first study to develop strategies for infection management using the CIMAS and RAFSI methods.

Keywords: infection management, health policy, health services, multi-criteria decision-making, fuzzy number

1. Introduction

Infection management is a set of systematic measures taken at the environmental, individual, and health services level to prevent and control the spread of infections and to apply the necessary treatments [1]. Infections are frequently encountered, especially in healthcare facilities. The rate of spread among people is also quite high. Therefore, infection management is necessary to prevent the spread of infections from getting out of control and to prevent outbreaks that may arise from this [2]. Effective infection management contributes to the diagnosis and treatment of diseases, improves people's quality of life, and reduces the workload of the healthcare system. However, if the process is not managed correctly, infection rates and outbreaks may increase in hospitals, antibiotic resistance may increase, and incurable diseases may occur. Therefore, individual and public health is under serious threat, and both economic and social costs increase. However, effective infection management can minimize these risks and create a healthy society. Therefore, it is important to manage the infection process with the right actions [3].

Many factors affect infection management in healthcare. The first of these factors is compliance with patient safety (CPS). In this context, the adequacy of sterilization practices, compliance of hand hygiene protocols with quality standards, and regular monitoring of infection rates are situations that need to be considered [4]. The qualification status of healthcare personnel also directly affects infection management. One of the most common reasons for the spread of infections is staff error or negligence. For this reason, it will be useful to increase the awareness of employees by providing appropriate training. In addition, employees need to work fully focused to reduce error rates. Therefore, extra workload negatively affects the process [5]. The presence of appropriate buildings and infrastructure in healthcare facilities is another important factor in the fight against infection. In

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this context, isolation and areas where medical devices are sterilized should be sufficient. At the same time, the presence of hygiene and cleaning infrastructure and the design of ventilation systems in areas where critical services such as operating rooms and intensive care are provided are also points to be considered for the process [6]. Utilizing developing technologies for infection management contributes to the process. Today, there have been many technological developments, such as data management systems, artificial intelligence, and antibiotic monitoring systems. These developments are essential to manage infection by taking it under control [7]. In addition, developing appropriate institutional and regional policies, evaluating environmental factors, and making the investments needed for infection management are other important factors [8].

Failure to control infection negatively affects patient and public health. In addition, in such cases, the sustainable service delivery of healthcare facilities is also disrupted. Therefore, it is important to examine the factors affecting the successful infection management process. There are a very limited number of studies addressing this issue in the literature. These studies mostly emphasize the importance of infection management. Many factors influence infection management. However, managers and policymakers cannot intervene in all these factors at the same time. This requires a lot of effort, time, and money. Accordingly, this study aims to develop a prioritized strategy for improving infection management processes in healthcare. The study answers the question, "What are the factors affecting infection management processes, and what should be the priority strategies for effective management of these processes?" Within the scope of the study, the CIMAS method is used for weighting the criteria. The CIMAS method also offers the possibility of performing reliability tests when determining weights. This allows the results to be verified. This feature has led to the CIMAS method being preferred in the analysis process. A set of alternatives is created for the criterion that affects the process the most. The set of alternatives shapes the most effective strategy for the most influential criterion. Alternative analysis is done with the RAFSI method. The RAFSI analysis process uses both normalization and standardization. This enables more accurate results to be obtained. For this reason, RAFSI has been preferred in the analysis process. In addition, expert selection is criticized in the literature. Indeed, experts have different work experience and competencies. For this reason, Z-scoring, which also takes into account the qualifications of individuals, is used in expert selection. Besides, not all data in the field of health management can be obtained quantitatively. Quantitative data can sometimes be susceptible to manipulation. Therefore, the aim is to obtain more realistic results by using a model based on expert opinions.

In the next section of the study, a literature review on the research topic is presented. In the third section, the methods used are explained in detail. Then, the findings obtained from the analysis are shared. The last sections include a discussion and a conclusion.

2. Literature Review

Effective infection management is closely linked to patient safety, as deficiencies in safety practices increase the risk of healthcare-associated infections and reduce the overall quality of care. Prior research demonstrates that strict adherence to patient safety protocols is essential for minimizing infection-related complications [9]. For example, Gaube et al. [10] reported inadequate hand hygiene compliance among outpatients, emphasizing the need for behavioral interventions to strengthen infection control. Similar findings were observed by Meenakshi Sundaram and Seethapathy [11], who showed that although personal protective equipment was available, audiologists in India demonstrated inconsistent glove use and limited hand hygiene practices. Likewise, Petrino et al. [12] highlighted persistent gaps in patient safety perceptions in European emergency departments and underscored the necessity of multifaceted strategies to improve infection-control performance.

Healthcare workers remain at constant risk of exposure to infectious agents, making personnel competence a central determinant of infection prevention [13]. Lee and Yang [14] found that nurses' infection-control performance was substantially lower than required and identified a critical need for structured training programs. Jolly et al. [15] demonstrated that healthcare workers' attitudes strongly influence adherence to infection-control protocols, while Gareeballah et al. [16] showed that those who received formal infection-control training achieved significantly higher knowledge scores, with female participants showing greater awareness than their male counterparts.

Beyond individual behaviors, organizational and managerial structures substantially influence infection management. In many public hospitals, infection control is coordinated by infection-control committees responsible for antimicrobial stewardship, sterilization oversight, and isolation protocols [17]. Alyahya et al. [18] examined implementation processes in sub-Saharan Africa and found that hospital leadership often failed to fully recognize the importance of systematic infection-control training. Ehsan et al. [19] showed that strong infection-control measures improved the quality of working life among healthcare workers in Jordan, reducing occupational stress and infection risk. Collaborative work between clinical teams has also been associated with better infection management outcomes.

Despite existing evidence, the literature remains limited in providing holistic frameworks that integrate multiple factors affecting infection management. Most studies focus on singular aspects, such as hand hygiene, training needs, or infrastructure quality. However, infection management is inherently multidimensional and benefits from approaches capable of evaluating multiple interdependent criteria.

In recent years, several advanced multi-criteria decision-making (MCDM) and fuzzy-based models have been proposed to support complex decision problems in healthcare and other sectors. Examples include interval-valued Fermatean neutrosophic hyper-soft sets [20], the AROMAN approach for evaluating sustainable strategies [21], hybrid fuzzy decision-map and gray relational analysis models [22], and gray-based MCDM methods for assessing technological priorities in healthcare [23]. Parallel developments in fuzzy decision-making such as type-2 fuzzy soft sets [24] and intuitionistic fuzzy parameterized soft-set scoring rules [25, 26] have further expanded the analytical capabilities for handling uncertainty and expert judgments.

Despite these methodological advancements, few studies have applied robust computational decision models directly to hospital infection management. Patient safety, qualified personnel, and appropriate infrastructure provide significant advantages for both healthcare professionals and patients by making infection control more effective. When the abovementioned factors are not well implemented or due to factors such as management deficiencies and financial constraints, the sustainability of infection-control measures becomes difficult. It may not be possible to intervene in all criteria affecting infection management in hospitals at the same time. Therefore, strategic plans should be developed by prioritizing among the identified criteria. Despite this, the number of studies addressing holistic approaches to infection management is insufficient in the literature. Existing studies generally emphasize the importance of infection control or address only a specific criterion. However, considering the multidimensional structure of infection management, comprehensive and integrated approaches are needed.

3. Research Methodology

A fuzzy decision-making model is proposed to determine the optimal strategy for infection management. Within the scope of this model, first, the selection of appropriate experts is performed with Z-scoring [27]. Then, the criteria affecting infection management are weighted with the help of the CIMAS method [28]. Finally, the optimal strategies are determined using the RAFSI method [29]. The uncertainty of the linguistic expressions in the model is integrated with the Pythagorean fuzzy numbers [30]. The flow of the fuzzy decision-making model is schematized in Figure 1.

3.1. Z-scoring

The objective determination of experts in MCDM analysis is crucial for the accuracy of the analyses [27]. Z-scoring is an approach that enables the determination of experts based on their qualifications. The steps involved in the Z-scoring process are summarized below. Equation (1) is used to create a data set related to the professional indicators of the experts.

$$\mathcal{A} = [a_{ij}] \tag{1}$$

In the subsequent analysis phase, the standardization process of the datasets is carried out. To be more precise, the standardization process of professional indicators is performed using Equations (2)–(4).

$$\bar{a}_j = \frac{\sum_{i=1}^{e} a_{ij}}{e} \tag{2}$$

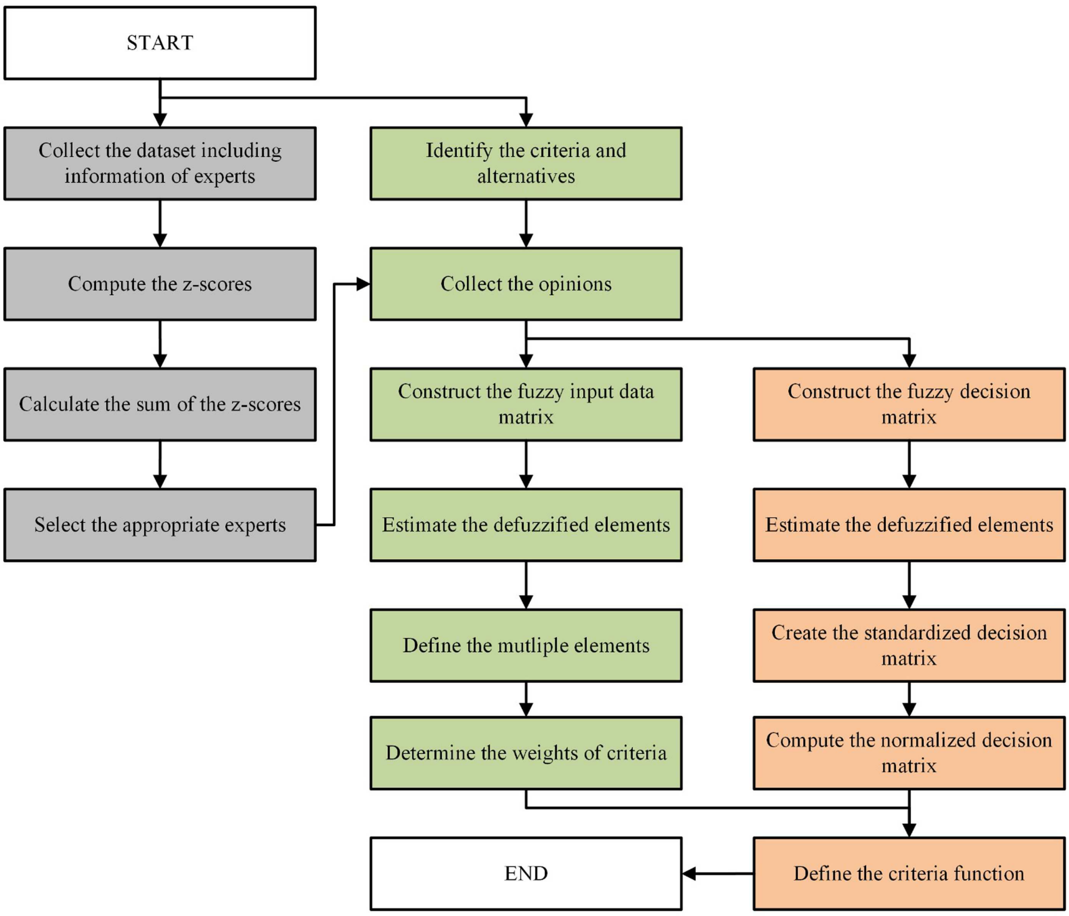
$$stdv_j = \sqrt{\frac{\sum_{i=1}^{e} \left(a_{ij} - \bar{a}_j\right)^2}{e}} \tag{3}$$

$$z_{ij} = \frac{a_{ij} - \bar{a}_j}{stdv_j} \tag{4}$$

The value e mentioned in these equations represents the number of experts. In the next step, the calculated Z-scores are summed using Equation (5).

$$Z_i = \sum_{j=1}^{k} z_{ij} \tag{5}$$

Figure 1
The flow of the fuzzy decision-making model



The k value specified in the equations represents professional indicators. In the Z-scoring analysis, experts with positive scores are finally identified. Opinions on the subject are collected from these experts.

3.2. Pythagorean fuzzy CIMAS

The CIMAS method is one of the preferred, up-to-date MCDM methods. It is a method that calculates criterion weights based on experts' evaluations. The most important advantage of the CIMAS method is that it can test the reliability of the results obtained [28].

Expert opinions are converted into fuzzy numbers to minimize uncertainty. Pythagorean fuzzy numbers were used in the analysis process. The linguistic equivalents of Pythagorean fuzzy numbers are presented in Table 1.

Table 1
Pythagorean fuzzy numbers

EL	0.1	0.99
VL	0.1	0.97
L	0.25	0.92
ML	0.4	0.87
M	0.5	0.8
MH	0.6	0.71
B	0.7	0.6
VT	0.8	0.44
TH	0.99	0

The details of the CIMAS calculation with Pythagorean fuzzy numbers are presented below. The creation of the criterion set is important at this point. After the criterion set is created, opinions are collected from experts using a nine-point scale. In the following process, the evaluations are converted into Pythagorean fuzzy numbers. Then, the input data matrix created is obtained using Equation (6).

$$\widetilde{\mathscr{A}} = [\widetilde{a}_{ij}]_{e \times n} \tag{6}$$

The n in the equation denotes the size of the criterion set $\widetilde{a}$ is a Pythagorean fuzzy number having degrees of membership (m) and non-membership (nm). In the subsequent analysis step, the normalization process is applied. Equation (7) is used to perform normalization.

$$\widetilde{n}_{ij} = \begin{cases} (m_{ij}, nm_{ij}) & for\ B \\ (nm_{ij}, m_{ij}) & for\ C \end{cases} \tag{7}$$

In the next step, the normalized values are multiplied by the coefficients from the expert assessments. Equation (8) is used for this step.

$$\widetilde{r}_{ij} = \mathbb{p}_i \widetilde{n}_{ij} = \left(\sqrt{1 - \left(1 - m_{ij}^2\right)^{\mathbb{p}_i}}, nm_{ij}^{\mathbb{p}_i} \right) \tag{8}$$

The weighted items are crisped using the score function in Equation (9).

$$r_{ij} = Sc\left(\widetilde{r}_{ij}\right) = 1 + m_{ij}^2 - nm_{ij}^2 \tag{9}$$

According to the analysis stages, the range between the maximum and minimum elements is determined. The range determination process is performed using the score values of the weighted elements. Equation (10) is used in this process.

$$L_j = \max\left(r_{ij}\right) - \min\left(r_{ij}\right) \tag{10}$$

Criterion weights are calculated in the final stage of the analysis. Equation (11) is used for this stage of the analysis.

$$w_j = \frac{L_j}{\sum_{j=1}^{n} L_j} \tag{11}$$

After the analysis stages are completed, the reliability of the results must be tested. Second assessments are collected to obtain a value of 100. Accordingly, the average value of the criteria is estimated. The reliability value is calculated using Equation (12) to obtain the RI value.

$$RI = \frac{\sum_{j=1}^{n} \left|100w_j - A.S.E_j\right|}{100} \tag{12}$$

At this stage, the A.S.E. value represents the average score of the criteria. For the reliability of the results, the RI value must be less than 0.1.

3.3. RAFSI

In the first stage of the RAFSI analysis, opinions are gathered from experts identified using Z-scoring. The collected opinions are converted into Pythagorean fuzzy numbers. Subsequently, they are multiplied by the coefficients of the selected decision-makers and summed with weighted fuzzy numbers [29]. In the next stage, Equation (13) is used to form the fuzzy decision matrix.

$$\tilde{D} = [\tilde{d}_{ij}]_{m \times n} \tag{13}$$

Equation (14) is used to calculate the crisped value of $\tilde{d}_{ij}$.

$$d_{ij} = scr\left(\tilde{d}_{ij}\right) = 1 + m_{\tilde{d}_{ij}}^2 - nm_{\tilde{d}_{ij}}^2 \tag{14}$$

For each criterion determined based on literature, the researcher determines d_{Ij} and d_{Nj}. d_{Ij} and d_{Nj} correspond to ideal and non-ideal values. The next step is to determine the criterion range for the decision matrix elements. Equations (15) and (16) are used for this purpose.

$$C_j \in \left[d_{Ij}, d_{Nj}\right]\ for\ Benefit \tag{15}$$

$$C_j \in \left[d_{Nj}, d_{Ij}\right]\ for\ Cost \tag{16}$$

The next step of the analysis is to map the subintervals to the criterion interval (($[n_1, n_{2k}]$)). This step is carried out using Equation (17).

$$f_s(x) = \frac{n_{2k} - n_1}{d_{Ij} - d_{Nj}} x + \frac{d_{Ij} n_1 - d_{Nj} n_{2k}}{d_{Ij} - d_{Nj}} \tag{17}$$

where $n_1 = 1$ and $n_{2k} = 6$ or $n_1 = 1$ and $n_{2k} = 9$. These functions are used to compute the standardized decision matrices. Equation (18) is used for this computation.

$$S = [s_{ij}]_{m \times n} \tag{18}$$

where $s_{ij} = f_{A_i}(d_{ij})$. The arithmetic (AM) and harmonic (HM) means of n_1 and n_{2k} must be calculated. The normalized decision matrix is obtained using Equations (19) and (20).

$$ns_{ij} = {}^{s_{ij}}/_{2AM} \text{ for Benefit } 4 \tag{19}$$

$$ns_{ij} = {}^{HM}/_{2s_{ij}} \text{ for Cost} \tag{20}$$

In the final stage of the RAFSI analysis, the normalized decision values are multiplied by the criterion weights. Equation (21) is used in this stage.

$$V_i = \sum_{j=1}^{n} CW_j \times ns_{ij} \tag{21}$$

4. Analysis

In this section, analysis outputs for infection management are presented with tables and figures.

4.1. Selecting of appropriate experts

The team, consisting of seven experts experienced in diseases and management of infectious, is analyzed using the Z-scoring method. To do this, first, a dataset containing the experts' age, income, sector, and total experience is created. The dataset is displayed in Table 2.

Table 2
Experts' age, income, sector, and total experience

	Age	Salary	Exp in sector	Total exp
Expert1	50	3300	27	30
Expert2	53	3400	30	33
Expert3	48	2700	25	28
Expert4	51	3000	28	31
Expert5	49	2850	26	29
Expert6	54	3400	31	34
Expert7	45	2500	23	25

The data in Table 1 are standardized. Then the sum of the standardized values is calculated. The sums of the experts' Z-scores are shown in Figure 2.

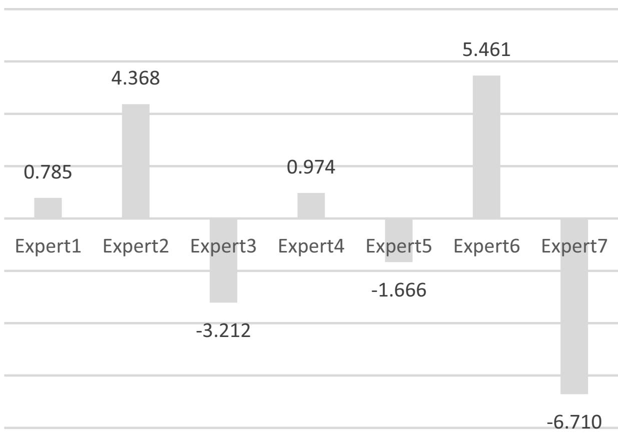
When Figure 2 is examined, experts who are positive are selected as appropriate experts. In this case, opinions are collected from Expert1, Expert2, Expert4, and Expert6 for analysis.

4.2. Weighting

The literature is reviewed, and factors affecting infection management are determined as CPS, qualification of personnel (QP), suitability of hospital infrastructure (SHI), use of advanced technology (UAT), management and organizational processes (MOP), financial adequacy level (FAL), and management of environmental factors (MEF). These criteria are evaluated by appropriate experts. These opinions are summarized in Table 3.

These opinions are transformed into the Pythagorean fuzzy numbers (Table A1). After that, these numbers are defuzzified.

Figure 2
The sums of experts' Z-scores



Next, the input data matrix is created, and the elements of the input data matrix are normalized by dividing by the sum of elements (Table A2 and Table A3). The weights of experts are determined according to experience in the sector of appropriate experts. The weights of experts are 0.233, 0.259, 0.241, and 0.267. The normalized elements are multiplied by the weights of appropriate experts (Table A4). Later, the differences between the maximum and minimum values of the criteria are computed (Table A5). Finally, the differences are normalized, and the weights of the criteria are defined. After defining the weights of the criteria, the second evaluation is collected to check the reliability index. The weights of the criteria, second evaluations, and reliability index are shared in Table 4.

According to RI in Table 3, the reliability index is checked since the value of RI is lower than 0.1. So, the most important criteria are CPS and the qualification of personnel.

4.3. Ranking

Alternatives, like criteria, are also determined. The alternatives for infection management are hygiene and handwashing training (HHWT), strengthening of infection control committee (SICC), implementation of sterilization and disinfection protocols (ISDP), management of antibiotic resistance and smart use of antibiotics (MARSUA), and patient education and participation (PEP). The alternatives are evaluated regarding the criteria by appropriate experts (Table A6). After that, the opinions are transformed into Pythagorean fuzzy numbers, and the averaged fuzzy numbers are computed. The fuzzy decision matrix is illustrated in Table 5.

Afterward, the elements of the fuzzy decision matrix are defuzzified (Table A7). For creating the functions, the ideal and anti-ideal of each criterion are determined as [.4, 1.9], [.5, 2], [.5, 1.8], [.4, 1.9], [.5, 2], [.4, 1.9], and [.5, 1.8]. The functions are defined as $f_1(x) = 3.33x - .33$, $f_2(x) = 3.33x - .67$, $f_3(x) = 3.85x - .92$, $f_4(x) = 3.33x - .33$, $f_5(x) = 3.33x - .67$, $f_6(x) = 3.33x - .33$, and $f_7(x) = 3.85x - .92$ for $n_1 = 1$ and $n_{2k} = 6$. Next, the standardized decision matrix is computed using these functions (Table A8). Later, the normalized decision matrix is calculated with arithmetic and harmonic means (Table A9). Finally, the criteria function of alternatives is estimated. The result is exhibited in Figure 3.

As can be seen from the values in Figure 3, the optimal alternatives are HHWT and SICC.

Table 3
The opinions about criteria

	CPS	QP	SHI	UAT	MOP	FAL	MEF
Expert1	EL	MH	M	B	TH	VT	B
Expert2	EL	MH	VT	ML	MH	M	MH
Expert4	VL	VL	VL	M	M	VT	MH
Expert6	TH	VT	VT	L	VT	B	B

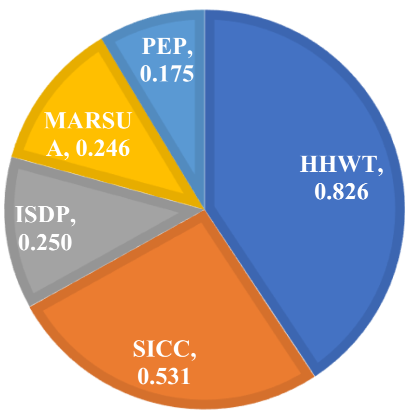
Table 4
Weights, second evaluations, and reliability index

	Weights	Expert1	Expert2	Expert4	Expert6	Average	RI
CPS	0.363	36	40	38	41	38.750	
QP	0.168	16	15	14	17	15.500	
SHI	0.152	15	13	12	15	13.750	
UAT	0.128	13	10	11	14	12.000	0.07
MOP	0.094	9	9	9	10	9.250	
FAL	0.061	6	8	8	2	6.000	
MEF	0.035	5	5	8	1	4.750	

Table 5
Fuzzy decision matrix

	CPS		QP		SHI		UAT		MOP		FAL		MEF	
HHWT	0.900	0.000	0.953	0.000	0.890	0.000	0.948	0.000	0.953	0.000	0.900	0.000	0.879	0.000
SICC	0.764	0.496	0.668	0.630	0.756	0.514	0.739	0.536	0.721	0.559	0.629	0.681	0.756	0.514
ISDP	0.454	0.834	0.487	0.810	0.536	0.770	0.650	0.658	0.609	0.701	0.528	0.776	0.554	0.754
MARSUA	0.594	0.716	0.487	0.810	0.465	0.821	0.465	0.821	0.488	0.804	0.401	0.864	0.537	0.764
PEP	0.401	0.864	0.465	0.821	0.441	0.833	0.429	0.846	0.600	0.710	0.488	0.804	0.455	0.828

Figure 3
The criteria function of alternatives



The strategic alternatives (e.g., hand hygiene training, disinfection protocols) discussed in the study were determined based on the World Health Organization's Core Components of Infection Control, literature review, expert opinions, and national guidelines. Although these practices may include overlapping components in the field, they differ in terms of scope of implementation, target group, and resource needs. While hand hygiene training targets individual behavior change and staff awareness, disinfection protocols are based more on managerial and infrastructural practices. Therefore, it was aimed to prioritize the practices that institutions may prefer under different conditions by differentiating the alternatives.

4.4. Sensitivity analysis

Sensitivity analysis for both the criteria and the alternative weightings is presented in Table 6.

As seen in the sensitivity analysis results, the ranking remains unchanged for both criteria and alternatives.

5. Discussion

This study aims to develop priority strategies to enhance the infection management process in hospitals. Nosocomial infections have become a significant global public health concern, leading to substantial economic losses across societies. In particular, the increasing number of hospitalized patients, the growing resistance of pathogens to antimicrobial agents, and the widespread use of these drugs have contributed to a rise in nosocomial infection rates. This increase not only prolongs hospital stays but also imposes an additional financial burden on healthcare systems. Preventing nosocomial infections requires the collective effort of not only healthcare professionals but also all hospital staff. In this context, it is essential to develop and implement effective strategies that ensure compliance among all employees.

The factors influencing the infection management process are analyzed, and "Compliance with Patient Safety Standards" emerged as the most critical factor. This finding indicates that patient safety measures should be approached systematically

Table 6
Sensitivity analysis

Criteria	Ranking for analysis	Criterion ranking for sensitivity analysis	Alternative	Ranking for alternative	Alternative ranking for sensitivity analysis
CPS	1	1	HHWT	1	1
QP	2	2	SICC	2	2
SHI	3	3	ISDP	3	3
UAT	4	4	MARSUA	4	4
MOP	5	5	PEP	5	5
FAL	6	6			
MEF	7	7			
CPS	8	8			

rather than on an individual basis. Thus, in addition to establishing patient safety policies, integrating these measures effectively into patient care processes is of paramount importance. The effectiveness of infection management policies has been well-documented in both national and international literature [30]. In addition, this finding is consistent with recent multi-criteria and multidimensional decision-making models in healthcare, such as interval-valued Fermatean neutrosophic approaches, which provide enhanced flexibility for modeling uncertainty and expert judgment in complex clinical environments [20].

However, the most decisive factor in the successful implementation of these policies is the level of knowledge and competence of healthcare professionals regarding infection prevention strategies [31]. Recent studies employing AROMAN, fuzzy–gray hybrid models, and various MCDM-based expert systems similarly emphasize the critical importance of the human factor; these approaches highlight that knowledge, skills, and professional competence remain central determinants within computational decision-making structures [21, 22]. Another key factor identified in the study, consistent with the existing literature, is the "Qualification Status of Healthcare Personnel." Regular and up-to-date training for all healthcare professionals is essential, with a particular emphasis on those working in high-risk areas such as sterilization units, emergency departments, intensive care units, and operating rooms [32]. Infection control requires a multidisciplinary approach. Therefore, infection-control teams must rigorously monitor and supervise critical aspects such as antimicrobial drug use, isolation protocols, and sterilization procedures to achieve the best results [33]. Furthermore, recent developments in gray-based MCDM methodologies demonstrate their applicability in analyzing complex operational processes in healthcare, supporting more structured monitoring and evaluation mechanisms relevant to infection-control systems [23].

A set of alternatives is developed for the most important criterion affecting infection management. The analysis of the set of alternatives shows what the most optimal practices are to improve infection management. The results of the analysis show that the optimal practice is "Hand Hygiene and Handwashing." Today, hand hygiene is regarded as one of the simplest yet most essential measures in infection prevention. However, compliance with hand hygiene protocols is directly correlated with the level of knowledge among healthcare professionals [34]. This observation aligns with recent intuitionistic fuzzy soft-set–based decision-making research, which models behavioral uncertainty in healthcare settings and enables more accurate analysis of awareness and compliance factors influencing infection prevention [25].

Objective studies among healthcare workers show that compliance with hand hygiene practices is inadequate [35]. Therefore, raising awareness of hand hygiene among healthcare professionals is fundamental to improving infection control. To achieve this, regular training programs should be implemented, real-time feedback mechanisms established, and automated monitoring systems utilized [36]. Additionally, increasing the accessibility of disinfectant dispensers throughout the hospital, conducting stringent audits, and enforcing compliance measures when necessary are critical steps in enhancing the overall effectiveness of infection management.

The findings of this study are broadly consistent with previous research, which has shown that infection management dynamics vary considerably across specialized clinical settings such as oncology, cardiac surgery, and transplant units, where heightened patient vulnerability and complex procedures require tailored infection-control strategies [10–12]. Similarly, the recommendation to integrate machine learning–based or computational expert selection mechanisms aligns with recent studies emphasizing that traditional expert selection approaches often fail to capture qualitative dimensions of expertise; contemporary work using interval-valued neutrosophic models, AROMAN-based evaluations, fuzzy–gray hybrid systems, and gray MCDM techniques demonstrates the need for more robust and adaptive methodologies in complex healthcare decision environments [20–23]. Furthermore, recent advancements in type-2 fuzzy soft sets and intuitionistic fuzzy parameterized soft-set decision frameworks provide additional mechanisms for modeling uncertainty and expert subjectivity, indicating that future extensions of the current model may benefit from incorporating these approaches [37]. Additionally, the suggestion to complement quantitative prioritization with qualitative insights from frontline healthcare workers is supported by prior research showing that operational workflow, communication patterns, and contextual factors significantly influence infection-control performance and cannot be fully captured by numerical methods alone [14]. Finally, applying the model across different countries aligns with global comparative studies demonstrating substantial international variation in infection-control infrastructure, staffing, antimicrobial-resistance patterns, and policy implementation, highlighting the importance of contextual validation in diverse healthcare systems [18].

6. Conclusion

Health services are of great importance for human health. However, it also involves risks due to the use of various medical materials in the service process. Especially in cases where medical waste is not managed properly and environmental impacts are not controlled, the incidence of infection increases. Infections can spread rapidly among people due to their nature. However, if proper infection management is provided, the safety of patients and healthcare workers increases, treatment times are shortened, and complications are prevented. At the same time, the burden on the health system is reduced. Therefore, it is important that infection management in healthcare services is carried out effectively and correctly. For this, it is necessary to examine the factors affecting the process and take actions to improve it. However, it is not possible to intervene in all existing factors at the same time. For this reason, it is necessary to know the importance of the factors to determine which action to take among the relevant factors. The aim of this study is to identify the factors affecting infection management processes in healthcare services and to rank their importance.

The results of the analysis show that patient safety compliance criterion is the most important factor affecting infection management in healthcare services. The quality of the staff and the suitability of the hospital infrastructure are the other most important factors. Focusing on the criteria that affect the most in this framework makes significant contributions to increasing the success of infection management in healthcare, ensuring patient and employee safety and the sustainability of the healthcare system. Hospital administrators should disseminate relevant protocols within the scope of quality standards, ensure compliance with hand hygiene standards, establish infection management committees, and ensure that infection rates are continuously monitored, and instant action is taken from this committee. For the staff, professional development and specialization training should be provided, motivational practices should be implemented, a multidisciplinary working environment should be created, and the workload should be reduced. In addition, the hospital building and infrastructure should be suitable for infection management. Isolation and cleaning areas should be designed correctly, sterilization areas should be adequate and appropriate, and ventilation systems should work actively. Compliance with these standards should be checked by an audit mechanism. At the same time, an investment fund should be established in the relevant field, and national resource allocation and incentive programs should be planned.

Within the scope of the study, alternatives are identified to improve CPS criteria, which is the most important of the criteria affecting the process to improve infection management. These alternatives are also ranked in order of importance. In the results of the analysis, HHWT is found to be the most important among the alternatives. While SICC ranked second, ISDP ranked third. As a result of the results obtained, both health managers can act on an institutional basis, and politicians can know where to intervene on a national scale. This significantly increases the likelihood of success in improving infection management. The investigation makes significant contributions to increasing patient and employee safety, combating epidemics, and efficiently using health resources. The recommended strategies may encounter certain obstacles during implementation. These obstacles may include insufficient financial resources, resistance to change within the organization, staff shortages, and inadequate control mechanisms, which should not be overlooked.

This study is conducted within the scope of general health services. The managerial processes of public and private hospitals may differ. This is an important limitation of the study. Evaluation of infection management processes specific to different hospital types may benefit the literature. In addition, detailed studies on each of the factors that are effective in the process make significant contributions to both the literature and practitioners. This study aims to guide decision-makers with an expert-based prioritization approach in a multidimensional and uncertain field such as infection management; at the same time, it prepares the ground for future studies by clearly pointing out the conceptual and structural limitations of the model. One of the most important limitations of the Z-scoring method is that it only selects experts based on numerical data. The Z-scoring method cannot weight titles, gender, or other non-numerical variables. This is one of the significant limitations of this approach. Except for this, one of the most important limitations of the MCDM approach is that it can only be used with quantitative data. Therefore, it is recommended that the results be supported by qualitative data.

This study was conducted in a developing country, and opinions were sought from experts with experience in that country. It is recommended that future studies be conducted specifically in developed and developing countries. Furthermore, experts conducted their evaluations based on general hospitals. It is recommended that studies be conducted for specialized hospitals, such as eye or heart hospitals. In addition, Z-scoring was used in the expert selection process. It is recommended that future studies use machine learning or artificial intelligence-based methods in the expert selection process.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Author Contribution Statement

Sefer Aygün: Conceptualization, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Sadiq Hussain:** Validation, Resources, Writing – review & editing, Visualization, Supervision, Project administration. **Yaşar Gökalp:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration. **Serkan Eti:** Methodology, Formal analysis, Writing – review & editing, Visualization. **Umutcan Altun:** Writing – original draft, Investigation. **Berkay Alikan:** Writing – original draft, Investigation, Writing – review & editing.

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Appendix

Table A1
Fuzzy input data matrix

	CPS		QP		SHI		UAT		MOP		FAL		MEF	
Expert1	.100	.990	.600	.710	.500	.800	.700	.600	.990	.000	.800	.440	.700	.600
Expert2	.100	.990	.600	.710	.800	.440	.400	.870	.600	.710	.500	.800	.600	.710
Expert4	.100	.970	.100	.970	.100	.970	.500	.800	.500	.800	.800	.440	.600	.710
Expert6	.990	.000	.800	.440	.800	.440	.250	.920	.800	.440	.700	.600	.700	.600

Table A2
Defuzzified matrix

	CPS	QP	SHI	UAT	MOP	FAL	MEF
Expert1	.030	.856	.610	1.130	1.980	1.446	1.130
Expert2	.030	.856	1.446	.403	.856	.610	.856
Expert4	.069	.069	.069	.610	.610	1.446	.856
Expert6	1.980	1.446	1.446	.216	1.446	1.130	1.130

Table A3
Normalized matrix

	CPS	QP	SHI	UAT	MOP	FAL	MEF
Expert1	.014	.265	.171	.479	.405	.312	.285
Expert2	.014	.265	.405	.171	.175	.132	.215
Expert4	.033	.021	.019	.259	.125	.312	.215
Expert6	.939	.448	.405	.092	.296	.244	.285

Table A4
Multiplied matrix

	CPS	QP	SHI	UAT	MOP	FAL	MEF
Expert1	.003	.062	.040	.111	.094	.073	.066
Expert2	.004	.069	.105	.044	.045	.034	.056
Expert4	.008	.005	.005	.062	.030	.075	.052
Expert6	.251	.120	.108	.024	.079	.065	.076

Table A5
Rmax, Rmin, differences, and weight values

	CPS	QP	SHI	UAT	MOP	FAL	MEF
Rmax	.251	.120	.108	.111	.094	.075	.076
Rmin	.003	.005	.005	.024	.030	.034	.052
Differences	.248	.115	.104	.087	.064	.041	.024
Weight	.363	.168	.152	.128	.094	.061	.035

Table A6
Opinions about alternatives

	CPS	QP	SHI	UAT	MOP	FAL	MEF
HHWT	TH	B	VT	B	TH	VT	B
SICC	VT	MH	VT	B	MH	MH	VT
ISDP	ML	MH	ML	B	B	ML	M
MARSUA	MH	ML	MH	L	B	ML	MH
PEP	L	MH	MH	M	MH	L	M
	CPS	QP	SHI	UAT	MOP	FAL	MEF
HHWT	B	TH	B	TH	B	TH	B
SICC	MH	VT	B	MH	VT	MH	B
ISDP	ML	ML	M	B	MH	B	M
MARSUA	B	ML	L	M	ML	L	L
PEP	ML	L	M	L	MH	M	M
	CPS	QP	SHI	UAT	MOP	FAL	MEF
HHWT	VT	TH	TH	TH	VT	VT	B
SICC	VT	MH	VT	VT	VT	MH	VT
ISDP	M	ML	MH	B	M	M	MH
MARSUA	ML	M	ML	MH	ML	ML	B
PEP	ML	M	L	M	MH	M	L
	CPS	QP	SHI	UAT	MOP	FAL	MEF
HHWT	VT	VT	B	B	TH	B	TH
SICC	VT	MH	B	VT	MH	B	B
ISDP	M	M	MH	ML	MH	ML	MH
MARSUA	MH	MH	M	ML	L	M	ML
PEP	M	ML	L	ML	MH	MH	M

Table A7
Deffuzified values

	CPS	QP	SHI	UAT	MOP	FAL	MEF
HHWT	1.810	1.908	1.792	1.899	1.908	1.810	1.773
SICC	1.338	1.049	1.308	1.259	1.208	.932	1.308
ISDP	.510	.581	.695	.989	.879	.676	.739
MARSUA	.840	.581	.542	.542	.591	.414	.704
PEP	.414	.542	.501	.468	.856	.591	.521

Table A8
Standardized matrix

	CPS	QP	SHI	UAT	MOP	FAL	MEF
HHWT	5.699	5.692	5.970	5.998	5.692	5.699	5.897
SICC	4.128	2.830	4.106	3.864	3.359	2.773	4.106
ISDP	1.368	1.271	1.750	2.962	2.263	1.922	1.920
MARSUA	2.466	1.271	1.160	1.472	1.305	1.048	1.785
PEP	1.048	1.139	1.003	1.228	2.186	1.637	1.079

Table A9
Normalized matrix

	CPS	QP	SHI	UAT	MOP	FAL	MEF
HHWT	.814	.813	.853	.857	.813	.814	.842
SICC	.590	.404	.587	.552	.480	.396	.587
ISDP	.195	.182	.250	.423	.323	.275	.274
MARSUA	.352	.182	.166	.210	.186	.150	.255
PEP	.150	.163	.143	.175	.312	.234	.154