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Journal of Computing Research and Innovation 9(2) 2024

Journal of Computing Research and Innovation

Ranking the Effective Non-Pharmaceutical Prevention Strategies Against COVID-19 Using Fuzzy Analytic Hierarchy Process Method

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ARTICLE INFO

Article history:
Received 22 June 2024
Revised 25 July 2024
Accepted 9 August 2024
Online first
Published 1 September 2024

Keywords:
COVID-19
Decision-making
FAHP
Prevention Measure

DOI:
10.24191/jcrinn.v9i2.454

ABSTRACT

As COVID-19 enters the endemic phase, public reluctance towards getting COVID-19 booster vaccinations presents a challenge for personal and public health. This hesitation increases the personal vulnerability to the virus and makes it more difficult to control the spread of COVID-19 across the community. Thus, this challenge underlines the need for alternate non-pharmaceutical preventive strategies. This study addresses the need by identifying and ranking the non-pharmaceutical preventive measures using the Fuzzy Analytic Hierarchy Process (FAHP) method. The FAHP approach utilises fuzzy logic to prioritise criteria and alternatives, offering a comprehensive assessment of preventative measures. We presented a case study where three experts were invited to rate three criteria and four alternatives using a nine-point scale with fuzzy numbers. The results indicate that alternative A_2 (social distancing) emerges as the most effective measure, while surprisingly, alternative A_3 (mask-wearing) is the least preferred. These rankings highlight the importance of effective non-pharmaceutical interventions to raise awareness and encourage people to take precautions in their daily lives during the endemic phase. Additionally, these findings provide the authorities with a valuable benchmark against future pandemics.

1. INTRODUCTION

It has been four years since the first coronavirus was identified in Wuhan, China, in December 2019. In the last seven days to 11 February 2024, 82,154 cases were reported to the World Health Organization (WHO), with 1,071 reported COVID-19 deaths (World Health Organization, 2024). The actual number of illnesses and fatalities from COVID-19 is anticipated to be greater than reported because of the relaxation of testing procedures. On 25 January 2020, Malaysia reported its first COVID-19 case (DG of Health, 2020). Since then, the country has seen a sharp increase in cases. However, the rollout of the vaccination plan in Malaysia

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https://dx.doi.org/10.24191/jcrinn.v9i2.454

on 24 February 2021 has remarkably mitigated the COVID-19 outbreaks. As of 25 February 2024, Malaysia recorded 8,236 active cases, with 8,113 cases (98.5%) quarantined at home, 120 cases (1.5%) hospitalized, 1 cases (0.01%) admitted to ICU without needing a ventilator, and 2 cases (0.02%) admitted to ICU requiring respiratory support (Ministry of Health Malaysia, 2024).

As COVID-19 enters the endemic phase, booster vaccinations are critical for personal and public health to decrease the number of fatalities, hospitalizations, and patients with serious illnesses. Despite the fact that mathematical (Hwang et al., 2023; Kin et al., 2023; Li et al., 2024; van Zoest et al., 2024) and medical (Ahn et al., 2023; Lee et al., 2023; Park et al., 2022; Shin et al., 2023) studies have shown the effectiveness of vaccination, people are still hesitant to take the booster vaccine. A systematic review by Limbu and Huhmann (2023) reviewed 42 eligible studies from PubMed, Medline, CINAHL, Web of Science, and Scopus, with 284,840 respondents across 25 countries, the East Mediterranean Region (EMR), Latin America and the Caribbean, showing that the average COVID-19 booster vaccination hesitancy rate was 30.72%. As of 26 November 2023, 13.6 billion COVID-19 vaccines have been administered globally since the rollout started, but only 32% of the total population has a booster dose across WHO member states (World Health Organization, 2023b). Meanwhile, Fig. 1 shows the percentage of the total population vaccinated with at least one booster dose of the COVID-19 vaccine; unfortunately, only 10 out of 179 member states achieved more than 70% of booster dose coverage. Thus, this hesitation underlines the need for alternate non-pharmaceutical preventive strategies.

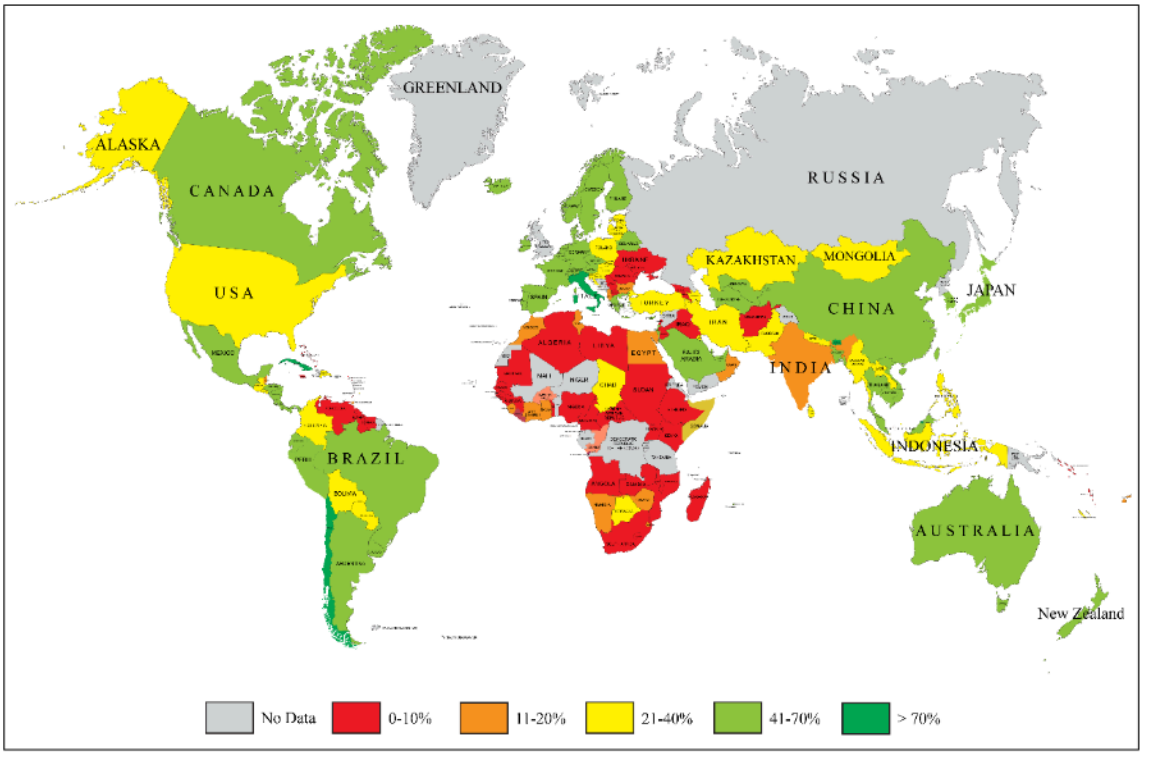

Fig. 1. Percentage of total population vaccinated with at least one booster dose of a COVID-19 vaccine.

Source: World Health Organization (2023b)

The public's doubts about the effectiveness of the COVID-19 vaccine, especially the booster dose, cause public hesitation toward the pharmacological preventive option (Shah & Coiado, 2022; Wong et al.,

https://dx.doi.org/10.24191/jcrinn.v9i2.454

2022). Furthermore, economically weaker nations cannot afford vaccines due to poverty, which worsens the situation (Hassan & Aliyu, 2022; Sheikh et al., 2021). Governments, policymakers, and individuals must understand and respond to these issues. Considering the individual's right to take the vaccine (Gostin et al., 2023; King et al., 2022) and underdeveloped countries' ability to access vaccine supplies (Burki, 2021), non-pharmaceutical interventions offer a practical alternative. Many studies show that non-pharmaceutical prevention measures significantly mitigate the spread of COVID-19 (Nahin et al., 2024; Nowak et al., 2023). These measures include hand hygiene, social distancing, mask-wearing and self-quarantine. Even the WHO has recommended these preventive measures, showing how vital hand hygiene, social distancing, wearing a mask and self-quarantine prevent the spread of this infectious disease (World Health Organization, 2023a).

However, several researchers have expressed that studies assessing the effectiveness of non-pharmaceutical interventions are inadequate (Samanlioglu & Kaya, 2020; Xie et al., 2022; Zheng et al., 2024). Most studies have only focused on using a quantitative approach to evaluate the effectiveness of non-pharmaceutical strategies against the spread of COVID-19. For instance, Alhomaid et al. (2024) employed simulation modelling to assess the efficacy of the non-pharmaceutical interventions implemented in the Kingdom of Saudi Arabia (KSA). To achieve their objective, they collected a large amount of weekly data on total cases, active cases, intensive care (ICU) admissions, and total deaths. Similarly, Ali et al. (2024) and Shimul et al. (2024) also adopted quantitative approach to model and investigate the effects of non-pharmaceutical interventions in limiting the spread of COVID-19 using incidence and death data from South Africa and Bangladesh, respectively. These studies typically focused on a quantitative approach where more extensive and precise datasets are needed for reliable and valid results. It is noticeable that these quantitative approaches overlooked the data collection via expert opinion.

Although some research has assessed the effectiveness of non-pharmaceutical interventions, it is worth noting that only a few studies have employed non-statistical approaches. As a result, this study aims to utilise a non-statistical approach in which data is gathered through expert judgement and the analysis is conducted using a preference-based fuzzy pairwise comparison technique. In particular, this study used the FAHP method to rank the non-pharmaceutical intervention strategies for containing the spread of COVID-19 and thus suggest the most effective intervention strategies.

2. METHODOLOGY

2.1 Experts and Nine-point Fuzzy Scale

We distributed a pairwise comparison questionnaire to three experts. They are guided to evaluate and compare pairs of criteria to each alternative to determine their relative importance using a nine-point fuzzy scale, as shown in Table 1.

Table 1. Nine-point fuzzy scale and its fuzzy numbers

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Scale	Linguistic terms	Triangular Fuzzy Number
1	Equally important	(1,1,1)
2	Between equally important and slightly more important	(1,2,3)
3	Slightly more important	(2,3,4)
4	Between slightly more important and obviously important	(3,4,5)
5	Obviously important	(4,5,6)
6	Between obviously important and strongly important	(5,6,7)
7	Strongly important	(6,7,8)
8	Between strongly important and extremely important	(7,8,9)
9	Extremely important	(9,9,9)

Source: Ayhan (2013)

This survey was conducted from December 11, 2023 to December 22, 2023 and Table 2 summarizes the concise biographies of the experts.

Table 2. Experts' biographical information

Biodata	Expert 1	Expert 2	Expert 3
Domain of expertise	Infectious disease	Public health	Nursing
Position	Senior assistant director	Medical officer	Senior staff nurse
Educational background	MBBCh	MD	Bachelor of nursing
Years of experience	10	21	12

At the beginning of the survey, all respondents were informed that their participation was entirely voluntary and anonymous. Once the respondents began answering the questionnaire, consent was inferred.

2.2 Criteria and Alternatives

In accordance with this study's objective, the criteria and alternatives were adapted and integrated from the published literature during the pandemic (Dashti et al., 2022; Niu & Scarciotti, 2022). The following are the criteria and their brief descriptions.

(i) Knowledge toward Covid-19 prevention measure (C_1): Awareness and understanding of practices to prevent the spread of Covid-19.

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(ii) Attitude toward Covid-19 prevention measure (C_2): Perceptions and feelings regarding the importance and effectiveness of Covid-19 prevention practices.

(iii) Practice toward Covid-19 prevention measure (C_3): Actual implementation and adherence to measures aimed at preventing the spread of Covid-19.

The public requires a scientific and practical approach to identifying the optimal non-pharmaceutical preventive measures to practice during the COVID-19 epidemic. The following is the list of alternatives.

(i) Hand hygiene (A_1): This practice aims to reduce the spread of COVID-19 by cleaning hands using water and soap or alcohol-based hand sanitizer.

(ii) Social distancing (A_2): This practice is intended to limit physical contact between individuals to slow down the transmission of COVID-19.

(iii) Mask-wearing (A_3): This practice involves using face coverings to limit the spread of COVID-19 through respiratory droplets.

(iv) Self-isolation (A_4): This practice refers to staying at home and avoiding interaction with people if experiencing symptoms or being diagnosed with COVID-19.

The criteria and alternatives were taken in pair-wise comparisons by three experts. Fig. 2 shows the hierarchy structure for the effective non-pharmaceutical prevention measures against COVID-19.

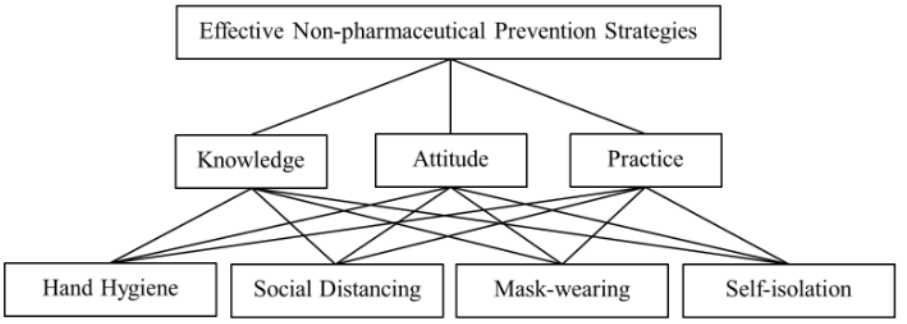

Fig. 2. Hierarchy structure for the effective prevention measures against COVID-19.

2.3 Computational Process

The FAHP proposed by Xu et al. (2023) was used to manage the uncertainty and subjectivity of decision-making in this study. We began by outlining and organizing the problem into a hierarchical structure of objective, criteria, and alternatives. Subsequently, we defuzzified these fuzzy comparisons to obtain crisp values. The weights for each criterion and alternative were then calculated. Finally, we ranked the alternatives based on the aggregated scores to help with decision-making. The flowchart of the computational process is depicted in Fig. 3.

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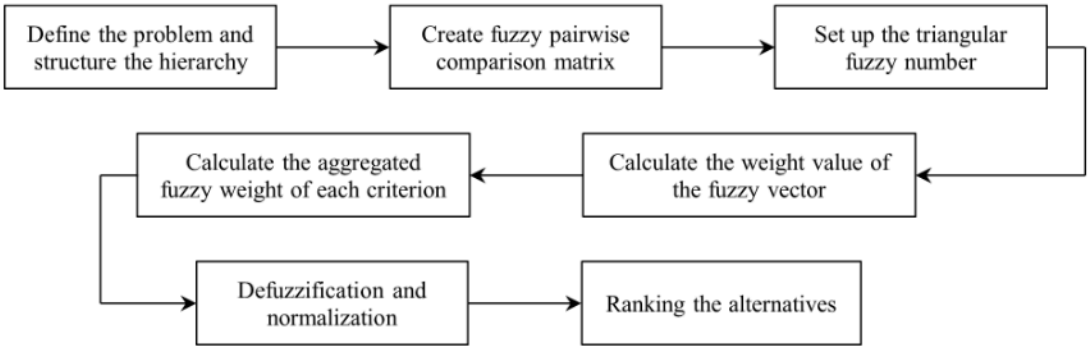

Fig. 3. Flowchart of the computational process.

The following describes details of the computational processes.

Step 1: Define the problem and structure the hierarchy

We organized the problem into a hierarchical structure with the objective at the top level, followed by the criteria of knowledge, attitude, and practice towards COVID-19. The bottom level is the alternatives for ranking the effective prevention measures against COVID-19.

Step 2: Create fuzzy pairwise comparison matrix

A fuzzy pairwise comparison matrix was developed using a scale of relative importance to determine the weights of criteria relative to the objective.

Step 3: Set up the triangular fuzzy number

Experts' responses to questions were used to determine the triangular fuzzy numbers for each criterion. The values of the FAHP scale (lower, L, median, M, and upper, U) were denoted as p, q, and r, respectively, with $p \leq q \leq r$.

Step 4: Calculate the weight value of the fuzzy vector using geometric mean method.

The geometric mean of fuzzy comparisons r_i was used to determine the fuzzy weight values. The process required converting AHP values to fuzzy AHP scale values and then calculating the geometric mean $\bar{d}_{ij}$ for the i-th criterion relative to the j-th criterion.

$$r_i = \left(\prod_{j=1}^{n} \bar{d}_{ij} \right)^{\frac{1}{n}}, \; i = 1, 2, \ldots, n \tag{1}$$

Fuzzy weights were then normalized by inverting and arranging the total fuzzy geometric mean values. The equation for inversed can be described as follows where l_i, m_i, and u_i are the components of the triangular fuzzy number for the i-th criterion, indicating the lower, median, and upper values respectively.

$$(l, m, u) = \left(\frac{1}{l_i}, \frac{1}{m_i}, \frac{1}{u_i} \right) \tag{2}$$

Step 5: Calculate the aggregated fuzzy weight for each criterion.

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The aggregated fuzzy weight $\tilde{W}_i$ for each criterion is calculated using the following equation where n denotes the total number of criteria and $\tilde{w}_{ij}$ is the fuzzy weight of the i-th criterion relative to the j-th criterion:

$$\tilde{W}_i = \frac{1}{n}\sum_{j=1}^{n}\tilde{w}_{ij} \tag{3}$$

Step 6: Defuzzification and normalization

Fuzzy weights need to be defuzzified using the center of area method as follows where p_i, q_i and r_i represent the lower, median, and upper values of the triangular fuzzy number for the i-th criterion:

$$W_i = \frac{p_i + q_i + r_i}{3} \tag{4}$$

The following process was to normalize the defuzzified weights for the i-th criterion W_i:

$$W_i = \frac{W_i}{\sum_{j=1}^{n} W_j} \tag{5}$$

Step 7: Ranking the alternatives

Finally, the alternatives were evaluated and ranked according to the aggregated scores. The weight of each alternative was determined by summing the weights of the individual criteria components, easing the decision-making process.

3. RESULTS AND DISCUSSIONS

The fuzzy analytic hierarchy process method is applied to select effective non-pharmaceutical prevention measures to prevent COVID-19 from spreading. Three experts, also known as the decision-makers in this study, evaluate the importance of alternatives with respect to criteria. There are four alternatives: hand hygiene, social distancing, mask-wearing, and self-isolation, and three criteria: knowledge, attitude, and practice, to consider and hence determine the best alternatives for the study. Based on the hierarchical structure shown in Figure 2, the top level is the study's objective. In contrast, the middle level showed the main criteria of the focus problem. As for the bottom level, four alternatives were determined to rank the effective non-pharmaceutical prevention measures.

The pair-wise comparison matrix, a key component of the fuzzy analytic hierarchy process method, was created for each criterion. This process used the fuzzy triangular numbers from each decision-maker, which were produced based on their preferences. The results of these comparisons are presented in Table 3, Table 4, and Table 5, providing a clear visual representation of the decision-making process.

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Table 3. Comparison matrix of criteria for decision-maker 1

Criteria	Knowledge (C_1)			Attitude (C_2)			Practice (C_3)		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Knowledge (C_1)	1	1	1	1	1	1	1	1	1
Attitude (C_2)	1	1	1	1	1	1	1	1	1
Practice (C_3)	1	1	1	1	1	1	1	1	1

Table 4. Comparison matrix of criteria for decision-maker 2

Criteria	Knowledge (C_1)			Attitude (C_2)			Practice (C_3)		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Knowledge (C_1)	1	1	1	0.25	0.33	0.5	0.33	0.5	1
Attitude (C_2)	2	3	4	1	1	1	2	3	4
Practice (C_3)	1	2	3	0.25	0.33	0.5	1	1	1

Table 5. Comparison matrix of criteria for decision-maker 3

Criteria	Knowledge (C_1)			Attitude (C_2)			Practice (C_3)		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Knowledge (C_1)	1	1	1	1	1	1	1	1	1
Attitude (C_2)	1	1	1	1	1	1	1	1	1
Practice (C_3)	1	1	1	1	1	1	1	1	1

Each value in the comparison matrix represents a ratio indicating the degree of preference for one criterion over another. The following is what the specific values represent:

(i) 1: This value indicates that the two criteria are equally important.

(ii) 2, 3, 4: These values indicate increasing levels of preference. For instance, the value of means that the row criterion is between equally important and slightly more important than the column criterion. At the same time, 3 indicates that the row criterion is slightly more important than the column criterion. Finally, 4 shows that the row criterion is between slightly more important and obviously important than the column criterion.

(iii) 0.25, 0.33, 0.5: These values represent the inverse preference. For example, 0.25 means that the column criterion is between slightly more important and obviously important than the row criterion, while 0.33 means that the column criterion is slightly more important than the row criterion. Lastly, the value of 0.5 indicates that the column criterion is between equally important and slightly more important than the row criterion.

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Next, the preferences of each decision maker were combined and averaged. This calculation resulted in Table 6, which shows a comparison matrix for the criteria after this averaging process.

Table 6. Comparison matrix of criteria after averaging

Criteria	Knowledge (C_1)			Attitude (C_2)			Practice (C_3)		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Knowledge (C_1)	1.00	1.00	1.00	0.75	0.78	0.83	0.78	0.83	1.00
Attitude (C_2)	1.33	1.67	2.00	1.00	1.00	1.00	1.33	1.67	2.00
Practice (C_3)	1.00	1.33	1.67	0.75	0.78	0.83	1.00	1.00	1.00

Averaging the preferences of the decision-makers is important as it ensures the final decision is balanced and unbiased, reflecting the collective judgement of the group. This process aids in reaching agreement, mitigating the influence of individual biases, and making decision-making more robust and inclusive.

In order to find the weight of each criterion, the geometric mean of fuzzy comparison values was calculated. Table 7 shows the geometric mean of fuzzy comparison values for each criterion by using Eq. (1).

Table 7. Fuzzy geometric mean for criteria

Criteria	Knowledge (C_1)			Attitude (C_2)			Practice (C_3)			Geometric mean of fuzzy comparison value		
	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper	Lower	Middle	Upper
Knowledge (C_1)	1.00	1.00	1.00	0.75	0.78	0.83	0.78	0.83	1.00	0.84	0.87	0.94
Attitude (C_2)	1.33	1.67	2.00	1.00	1.00	1.00	1.33	1.67	2.00	1.21	1.41	1.59
Practice (C_3)	1.00	1.33	1.67	0.75	0.78	0.83	1.00	1.00	1.00	0.91	1.01	1.12
							Total			2.96	3.29	3.65
							Inverse			0.3378	0.3040	0.2740
							Increasing order			0.2740	0.3040	0.3378

Then, the aggregated fuzzy comparison value was inversed using Eq. (2) to maintain the reciprocal property. This process ensures that the aggregated values accurately reflect the relative importance of criteria as well as the collective judgment of the decision-makers. The inversion values were arranged in ascending order for maintaining the proper structure of fuzzy triangular numbers.

Next, the fuzzy weight of each criterion was calculated by using Eq. (3). The relative fuzzy weight was then defuzzified using the centroid method from Eq. (4). The relative fuzzy weight and the defuzzified weight of each criterion are shown in Table 8.

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Table 8. Relative fuzzy weight and defuzzified value of each criterion

Relative fuzzy weight			Defuzzified
Lower	Middle	Upper	
0.23	0.26	0.32	0.27
0.33	0.43	0.54	0.43
0.24	0.30	0.37	0.30
	Total		1.00

The total of 1.00 in Table 8 indicates that the weights are correctly normalized. It shows that the relative importance of the criteria is accurately represented and that the decision-making process is based on a consistent and interpretable set of weights.

After going through the FAHP synthesis, the final weights and ranking of the alternatives are shown in Table 9.

Table 9. Final weights and the ranking of the alternatives

Alternative	Knowledge (C_1)	Attitude (C_2)	Practice (C_3)	Overall score	Ranking
Hand hygiene (A_1)	0.29	0.40	0.20	0.3103	2
Social distancing (A_2)	0.42	0.21	0.36	0.3117	1
Mask-wearing (A_3)	0.15	0.15	0.28	0.1890	4
Self-isolation (A_4)	0.15	0.24	0.16	0.1917	3

Based on Table 9, social distancing is the most preferred non-pharmaceutical prevention strategy against the spread of COVID-19 followed by hand hygiene, self-isolation, and mask-wearing.

As the world navigates through the endemic phase of COVID-19, non-pharmaceutical prevention strategies become vital in mitigating its spread. Our study showed that social distancing is the most effective non-pharmaceutical prevention strategy. This finding is consistent with the recommendation of the Centers for Disease Control and Prevention (CDC), suggesting that minimizing interpersonal interactions is the most effective method to mitigate the transmission of COVID-19 (Centers for Disease Control and Prevention, 2020). A study of 211 counties in 46 states across the United States found that social distancing, moderate temperature, and lower population density were linked to a decline in the reproduction number of COVID-19 (Rubin et al., 2020). The data suggests that social distancing strongly correlated with decreased virus transmission. Similarly, a socioeconomic analysis by Lopolito et al. (2024) suggested that moderate social distancing can avoid economic catastrophes caused by productivity losses while slowly restoring critical social interactions.

Interestingly, our study yielded an unexpected finding where mask-wearing was the least effective measure among the other strategies. This result, while surprising, aligns with the findings of a randomized controlled trial conducted in Denmark during the initial phases of the pandemic (Bundgaard et al., 2021). The study suggested no statistically significant decrease in COVID-19 infection rates among mask users, raising questions about the perceived benefits of mask use. This scenario prompts us to consider other prevention measures that may be more effective in reducing virus transmission. Furthermore, work from

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Klompas et al. (2020) highlighted that mask-wearing outside medical facilities offers minimal to no protection against the infection. They further argued that wearing a mask alone will only marginally lower the risk of infection since it does not protect against airborne transmission that may penetrate the eyes or viruses may be caught on hands and transmitted to mucous membranes.

According to the experts in this study, COVID-19 prevention also requires hand hygiene and self-isolation. Regular hand washing with soap and water, or hand sanitizers kills the virus and limits its entry into the body. Individuals who are positive or exposed to the virus should self-isolate to reduce person-to-person transmission and break the transmission cycle. These behaviors, together with social distancing and mask-wearing, collectively serve as the cornerstone of public health approaches to contain the epidemic.

4. CONCLUSION AND RECOMMENDATIONS

Knowledge, attitudes, and practices (KAP) about COVID-19 substantially impact society's preparedness to respond to behavioral interventions from health authorities. Studies on KAP regarding COVID-19 have provided data that can be used to determine the type of interventions needed to bring the virus to the public's attention. In this study, the problem of ranking the effective non-pharmaceutical prevention strategies against COVID-19 has been solved using the FAHP method. This study shows that knowledge, attitude, and practice are relevant as a weight, and social distancing is the most preferred strategy against the spread of COVID-19. This study's incapacity to evaluate the efficacy of various non pharmaceutical intervention combinations was one of its limitations. Therefore, further studies can be focused on the effectiveness of various non-pharmaceutical intervention combinations against COVID-19. Finally, a combination of non-pharmaceutical preventive measures, including social distancing, mask wearing, hand hygiene, and self-isolation, constitute an effective way to reduce the transmission of COVID -19 and should not be utilized separately.

5. ACKNOWLEDGEMENTS/FUNDING

The authors would like to acknowledge the support of Universiti Teknologi Mara (UiTM), Cawangan Perlis, Kampus Arau and College of Computing, Informatics, and Mathematics, UiTM Cawangan Perlis for providing the facilities on this research.

6. CONFLICT OF INTEREST STATEMENT

The authors agree that this research was conducted in the absence of any self-benefits, commercial or financial conflicts and declare the absence of conflicting interests with the funders.

7. AUTHORS' CONTRIBUTIONS

Teoh Yeong Kin: Conceptualisation, data curation, formal analysis, investigation, methodology, project administration, writing-original draft, writing-review & editing; **Suzanawati Abu Hasan**: Conceptualisation, methodology, and writing-review & editing; **Nor Azriani Mohamad Nor**: Data curation, formal analysis, and writing-review & editing; **Anas Fathul Ariffin**: Investigation, and writing-review & editing; **Lee Joo Ann**: Formal analysis, and writing-review & editing; **Nur Afifah Zabidi**: Writing-review & editing.

https://dx.doi.org/10.24191/jcrinn.v9i2.454

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