International Journal of Economics, Commerce and Management
United Kingdom ISSN 2348 0386 Vol. X, Issue 10, Oct 2022

http://ijecm.co.uk/

SELECTION OF COVID-19 RTK-AG TEST KIT USING BEST -WORST AND VIKOR METHOD

Hamidah Maidinsah
Faculty of Computer and Mathematical Sciences
University of Technology MARA, Selangor, Malaysia
hamidah@tmsk.uitm.edu.my

Marina Mahajid
Faculty of Computer and Mathematical Sciences
University of Technology MARA, Selangor, Malaysia

Abstract

Malaysia entered the endemic phase in April 2022 after battling the Covid-19 pandemic for more two years. Malaysians are advised to depend less on RT-PCR testing and more on self-testing kits, which have recently become immensely available. There are various test kits available in the Malaysian market, each with different pricing, level of sensitivity and sample type, including nasal and saliva specimens. This research aims to evaluate the most important criteria in selecting RTK-Ag Covid-19 test kits and the most preferred test kits product. The respondents were 40 Covid-19 patients and medical experts in Klang Valley. The Best Worst Method was used to measure the weight of five preference criteria, namely cost, sensitivity, advertising, accessibility, and practicability. The VIKOR technique rates the six alternatives offered. The results reveal that sensitivity is the most significant criterion since sensitivity can ensure a person is infected or not followed by usability, cost, accessibility and advertising. The most preferred alternatives for RTK-AG test kit are A_5 with a sensitivity 91.38% and the price is as cheap as RM5.96 followed by A_6, A_4, A_2, A_3 and A_1. The results can give some information to consumers and marketing officers on which products are cost-effective and likely to be purchased.

Keywords: Multi Criteria Decision Making, Best Worst Method, VIKOR Method, COVID-19, RTK-Ag test kit

INTRODUCTION

The World Health Organization (WHO) has declared a public health emergency due to Coronavirus 2019 or Covid-19 by the end of 2019. Coronavirus disease is an infectious disease caused by the SARS-CoV-2 virus that has swiftly spread across the globe with more than 100 million cases recorded and a global mortality toll of more than 2 million. As of 13th July 2022, Malaysia has over 4.6 million confirmed cases of Covid-19 and over 35,800 deaths from the virus. Malaysia has successfully vaccinated approximately 83.7% of its population with at least two doses, despite an increase in infections caused by the particularly contagious Omicron strain (Hirschmann, 2022). According to the most current (seventh) edition of the Chinese government's guideline for the diagnosis and treatment of pneumonia caused by Covid-19, the diagnosis of Covid-19 must be confirmed by reverse transcription-polymerase chain reaction (RT-PCR) or gene sequencing (Zhou et al., 2020).

Malaysia is transitioning into the endemic phase in April 2022, at which point the illness will likely remain in a lesser form. Symptoms may appear between two to fourteen days following exposure to the virus. Patients with Covid-19 may develop symptoms like fever or chills, cough, shortness of breath, exhaustion, and muscular or body aches. The symptoms include headache, loss of taste or smell, sore throat, congestion or a runny nose, nausea or vomiting, and diarrhea. The severity of the sickness may lead to respiratory distress or respiratory failure, demanding the use of an intensive care unit (ICU). The severity of the disease is correlated to the age and comorbidities of the infected person; older adults are significantly affected and need intensive care (Kamal et al., 2020).

There are several products and qualities to consider when selecting an RTK-Ag test kit from numerous countries of origin. Detection of the nucleic acids of the virus's RNA or antibodies generated by the patient's immune system. In mathematical modelling, the Multi-Criteria Decision-Making (MCDM) technique analyse several criteria and choosing the best alternatives is widely used in various sectors (Wu et al., 2019). MCDM is one of the most popular techniques to resolve disagreements and considered as a dynamic and complex procedure with management and engineering levels (Opricovic & Tzeng, 2004).

Problem Statement

There are several test kits on the Malaysian market, each with a different quality. In addition, there are currently two types of RTK-Ag test self-test kits (RTK) available, one of which needs a nasal specimen through an anterior nasal swab or a nasal mid-turbinate swab and the other of which requires a saliva specimen. The RTK generates outcomes within 15 to 30 minutes, which is much faster than the RT-PCR test. If handled correctly, the results are nearly

comparable to the RT-PCR test. It is unknown how consumers evaluate and act upon the findings of Covid-19 home self-tests. A negative test result may promote dangerous behaviour in users if they disregard this potential. It is important to know the criteria in selecting a test kit in terms of accuracy and sensitivity for identifying SARS-CoV-2. for research marketing purposes.

Research Objectives

The research objectives are to evaluate the most important criteria in selecting the RTK-Ag test kit and to determine the most preferred alternatives or products available from the market. Research on the selection of RTK might provide customers with relevant details and information for choosing an efficient test kit in an effort to reduce false-negative results. RTK has become a requirement for every household. It is crucial when picking between alternatives based on personal preferences and available funds. Besides sensitivity and price, this research considers a few test kit characteristics based on the product identification itself. Advertising, usability, and accessibility may be used as performance indicators for the test kits. As a result, evaluating the prospects of the RTK in Malaysia is essential, as it would be advantageous to consumers.

Significant, Scope and Limitations of Study

The study only focuses on the MCDM model specifically. It proposes a systematic and scientific method composed of the hybrid Best Worst and VIKOR methods in criteria and alternatives selection respectively. Both BWM and VIKOR methods rely on experts or experienced persons to reduce the degree of conflict among decision maker and produce more consistent results (Gupta, 2017; Calik 2020). Former Covid-19 patients have more experience monitoring test kit results to determine whether the detection is accurate when they have symptoms. As experts in medical concerns, medical professionals are better knowledgeable about Covid-19 test kits and their opinion is very relevant. The criteria and alternatives are defined based on a commercial website, a random post on social media from Twitter regarding the test kit's accuracy and previous research on product marketing. Only five criteria such as cost, accessibility, advertising, and practicality or usability were considered in this study for selecting an RTK including detection range and sensitivity limitations. Only six alternatives of RTK that are available in the market were surveyed.

LITERATURE REVIEW

Since the commencement of the Covid-19 pandemic, laboratories have performed nucleic acid amplification tests (NAATs), such as RT-PCR assays, to identify SARS-CoV-2 (WHO, 2021). In an emergency, the RT-PCR test may be useless due to its potential

prolonged turnaround time. It also requires costly equipment and trained personnel, none of which may be accessible in rural health clinics, especially in developing countries (Khandker et al., 2021). RTK has emerged as a key alternative diagnostic instrument for Covid-19. The RTK-Ag test is based on immunochromatography, which includes the detection of antibodies on nitrocellulose membranes that interact with specific antigens from a patient's sample. There is an RTK-Ag test for determining the composition of the SARS-CoV-2 antigen. The RTK-Ag test results are obtained within 30 minutes and may be assessed without the requirement for a specialised apparatus (Mak et al., 2020). Both types of Covid-19 tests have the same objective in diagnosing active SARS-CoV-2 infection using nasal and throat swabs and nasal and saliva specimens, respectively. RTK tests are self-administrable, but PCR tests need expert administration. Comparatively, the PCR test takes a much longer turnaround time than test kits. RTK-Ag is more reasonable than RT-PCR in terms of price, and it is available in both physical and online stores. Although RT-PCR does not produce rapid results, it is recognised as the "gold standard" for Covid-19 identification during the pandemic due to its greater accuracy.

In 2022, the Medical Device Authority (MDA) under the Malaysian Ministry of Health announced the following list of 125 RTK-Ag test kits that were approved for Conditional Approval based on the recommendation of the Covid-19 Test Kit Expert Committee. First, all test submissions are rated based on the manufacturer's clinical and technical performance proof. Second, the assessment test results from testing facilities agree with the committee evaluation criteria defined by clinical expert panels, and third, the Covid-19 IVD Test Kits Conditional Approval Supporting Documents. In the meantime, RTK should only be used for screening purposes, and all test results should be validated by RT-PCR. The testing kits are also available in supermarkets, convenience stores, and petrol stations. Most of the RTK chosen offered 100% specificity at varying sensitivities and costs. The pricing was obtained from two separate sources, rapidtestkit.com.my and watsons.com.my. It was identified based on price variation, sensitivity, and sampling method. One of the considerations in selecting Covid test kit is usability. RTK Antigen Test is a fast test for detecting SARS-CoV-2 antigens in human saliva and nasal samples. This test kit is easy to use (user-friendly), non-invasive, and may be self-administered in about 15 minutes. Every package has clear steps and instructions for the user to follow. Furthermore, the test kit is small enough to carry with you everywhere you go as a precaution. The government has established the maximum ceiling pricing for RTK based on The Syafiqah (2021), with the wholesale price set at RM16 per unit and the retail price set at RM19.90 per unit. It has been observed that the pricing of RTK is influenced by sample type, sensitivity, and country

of manufacture. The sensitivity and accuracy of RTK were established as a valid method of diagnosing Covid-19. Users are more likely to choose well-advertised RTK for ads because they look more appealing to them, they often choose products with which they are already familiar. Since RT-PCR are not available everywhere, the RTK is practical, and easy to use with the steps given and can be performed anywhere without needing to get tested at a healthcare facility. Finally, there is accessibility. Customers choose RTK readily available in their areas during an emergency.

Multiple-Criteria Decision-Making (MCDM)

According to Lwin (2018), MCDM is designed to aid decision-makers who must make diverse and contradictory assessments. The objectives of MCDM are to highlight these issues and propose a means to find a clear settlement. Approaches based on MCDM are often used to address complex problems that need the assessment and selection of appropriate solutions based on the performance of alternatives in reference to aid-defined criteria. Value measurement models, goal aspiration and reference level models, and outranking models are the three categories of MCDM models. An MCDM tool might assist companies with their fresh product selection and grading operations in their food supply chains. The recommended new product evaluation framework includes a broad, systematic design that integrates with the conventional human measurement process for determining the quality and acceptability of various fresh products (Leung et al., 2020).

Application of Best Worst Method (BWM) and VIKOR Method

Rezaei's (2015) Best Worst Method (BWM) framework has been frequently used to determine the weight of criteria selection. BWM gives more consistent results and requires fewer data and fewer pairwise comparisons (Çalik, 2020), while the VIKOR method was developed to optimise complicated systems based on several criteria. It computes the compromise ranking list, the compromise solution, and the weight stability intervals for the preference stability of the compromise solution generated with the original (supplied) weights. It provides the multicriteria ranking index, which is based on a particular measure of "closeness" to the "ideal" option (Opricovic & Tzeng, 2004). BWM uses include analysing energy efficiency limitations, external influences in the oil and gas industry, supplier selection, and evaluating the effectiveness of university-industry Ph.D. courses (Ahmadi et al., 2017).

Gupta (2017) introduces a unique technique that combines the BWM and VIKOR approaches, which have been shown to produce more consistent findings and save time for

decision-makers. BWM is used to rank service quality criteria and VIKOR methodology is used to rank the best airline in terms of these attributes. Tangibility, reliability, security and safety, and ticket price are discovered to be the most key aspects of service quality, and subsequent analysis utilising. The method does not require a huge sample size for analysis. The results of the study can be further confirmed by performing a longitudinal study with a suitably enough sample size. Çalik (2020) conducted a study on the evaluation of social media networks using the BWM and VIKOR. There are several ways for a travel firm to increase its presence on social media. BWM and fuzzy VIKOR is used to determine the best social media sites. By using BWM, the weights of nine criteria specified by the literature survey and expert interviews were derived. Then, weights were then used with fuzzy VIKOR to rank social media networks. The cost criteria were found to be the most important factor with the audience ranking second. Since the VIKOR model yielded ideal results, the methodology has been widely applied to material selection decisions, such as the femoral component of a knee replacement in the medical field, the rigid pin of a shaft, and the selection of structural elements with high safety requirements in the aerospace and nuclear industries (Anojkumar et al., 2014).

Rafieyan et al. (2020) conducted research on an adaptive scheduling technique for cloud computing based on BWM and VIKOR. Cloud computing is an emerging distributed environment that provides on-demand services through the internet and has grown in popularity because of this characteristic. By increasing the number of user requests and different criteria for using cloud resources, there are issues in handling these requests and allocating them optimally. To indicate task priorities, the VIKOR approach is used as a decision-maker. The findings indicated that the suggested technique increases performance indicators such as waiting time, virtual machine (VM) consumption, and VM utilisation cost. Kumar et al. (2020) investigated the criteria for measuring airports' green performance. To determine the weight of several factors and rank the airports, a hybrid of BWM and VIKOR techniques was used. The most essential performance factors for green airports are green policies and regulations. Abdulkareem et al. (2020) conducted a study using BWM and VIKOR to provide a unique multi-perspective benchmarking framework for selecting the best image dehazing intelligent algorithm. Several views, such as inhomogeneous foggy, homogeneous foggy, and dark foggy situations were considered. Experiments were carried out in three stages such that, an evaluation with five algorithms as part of matrix data, combining picture dehazing intelligent algorithms with a set of goal assessment criteria to obtain matrix data, and ranking the picture dehazing intelligent algorithms. Parhizgarsharif et al. (2019) introduced a new hybrid framework consisting of the Best Worst Method

(BWM), Gray Relational Analysis (GRA), and VIKOR to identify potential site layout locations in Tehran, Iran. The appropriate site plan sites were established as potential alternatives and ranked by specialists depending on the structure. The weights of the selected nine criteria (cost, safety, etc) were calculated using BWM and ranking of the locations was accomplished using two GRA and VIKOR methods. Both results from VIKOR and GRA approaches produce the same ranking.

Nadzira Amanina (2020) researched the coffee chain preferences of students based on several parameters using the Principal Component Analysis, Best Worst Method, and Simple Additive Weighting. One of the goals of this study is to rank the six criteria, namely customer service, flavour variety, accessibility, pricing, advertising, and HALAL certification. Halal certification was the most important factor, followed by customer service, pricing, accessibility, marketing, and flavour variation. Hamidah, Nurin Fatini, and Nur Nadia (2021) used BMW in selecting criteria for home broadband plans and determining the most preferred plan among 50 university students in open and distance learning classes during the Covid-19 pandemic period. They found that reliability is the most significant criterion followed by accessibility, cost, customer service, and advertisement.

RESEARCH METHODOLOGY

This study used a quantitative approach. An online survey was circulated through social media sites to researcher personal contacts. Respondents were a total of 40 ex-Covid-19 patients and medical personnel. The instrument (Appendix A) has three parts. Part A required respondents to indicate the most and least important selection criteria as listed in Table 1 for test kits. Parts B and C consist of Likert scale questions ranging from 1 to 9 points. Part B is a pairwise comparison question. Part C included respondents' evaluations of six test kits type, precision and pricing as listed in Table 2.

Table 1: Criteria and Description of of RTK

Criteria		Description
Cost	C_1	The price of the Covid-19 RTK antigen self-test kit.
Sensitivity	C_2	The accuracy of the Covid-19 RTK antigen self-test kit.
Advertising	C_3	The public notice about a product (cost, sensitivity & sampling type).
Practicality/Usability	C_4	Easy to use (nasal or nose),
Accessibility	C_5	Easy to obtain in-store or online

Table 2: Description of RTK (Rapidtestkit.com.my, watson.com.my)

Alternatives	Sample Type	Sensitivity	Price (RM)
A_1	Saliva and nasal swab	91.4%	19.90
A_2	Saliva and nasal swab	91.67%	6.90
A_3	Saliva and nasal swab	93.3%	8.50
A_4	Saliva	100%	6.90
A_5	Saliva	91.38%	5.96
A_6	Saliva	96.7%	6.90

Data Analysis

The collected data for BWM, were coded into Microsoft Excel's Data Solver to generate a result, while VIKOR computation used Microsoft Excel formulas. BWM is used to calculate the weight of the five criteria while VIKOR method is used to rank the six alternatives.

IMPLIMENTATION OF BEST-WORST AND VIKOR METHODS

The following are the three steps in calculating criteria weights using BWM (Çalik, 2020):

Step 1: Selection of best and worst criteria.

The decision-maker decided on the best (most important, BO) and worst (least important, OW) criteria.

Step 2: Pairwise comparison, BO and OW

A discrete pairwise comparison scale on a range of 1 (equally important) to 9 (extremely important), was given for preference ranking. Respondents choose a scale for the important criteria. Respondents made the comparison between the best criterion (B) with other criteria (O). The resulting vector is called the best-to-others vector (1).

$$A_B = (a_{B1}, a_{B2}, \cdots, a_{Bn}), \quad (1)$$

where a_{Bj} indicates the preference of the best criterion B over criterion j and this situation $a_{BB} = 1$ because it gives equal importance between the best and most preferred criterion.

Respondents made the comparison between other criteria (O) and the worst criterion (W). The resulting others-to worst vector is in (2).

$$A_W = (a_{W1}, a_{W2}, \cdots, a_{Wn})^T, \quad (2)$$

where a_{Bj} indicates the preference of the best criterion j over the worst criterion W and this situation $a_{WW} = 1$ because it gives equal importance between the best and most preferred criterion.

Step 3: Evaluate weightage for each criterion.

The optimal weights for each criterion $(w*_1, w*_2, \cdots, w*_n)$, determined by the maximum absolute differences of $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ for all j should be minimised, are translated to the min-max model in the model (3) and (4);

$$min\ max_j \left\{\left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{jW}\right|\right\}$$

s. t. (3)

$$\sum_{j=1}^{n} w_j = 1$$

$w_j \geq 0$,for all *j*.

Model (3) can be transformed into the following problem:

min ξ

s. t

$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi$, for all *j* (4)

$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi$, for all *j*

$$\sum_{j=1}^{n} w_j = 1$$

$w_j \geq 0$, for all *j*.

By solving model (4), the optimal weights $(w*_1, w*_2, \cdots, w*_n)$ and the optimal value of pairwise consistency ξ can be obtained, where ξ is given as equation (5). The closer the value of ξ to 0, the greater the consistency and the more reliable the comparison becomes.

$$\xi = \frac{\lambda\ max - n}{n - 1} \quad (5)$$

The following are the eight steps in ranking the alternatives using VIKOR method (Parjizgarsharif et al. 2019):

Step 1: The decision matrix $D = [x_{ij}]$ is constructed as (6):

$$C_1 \quad C_2 \quad \ldots \quad C_n \quad (6)$$

$$D = \begin{matrix} A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix},$$

where $A_1, A_2, \cdots, A_m$ are the possible alternatives selected in this study while $C_1, C_2, \ldots, C_n$ represents the extracted decision criteria while x_{ij} represents the performance scores of every criterion towards the selected alternatives for all values of $i = 1,2,3, \ldots, m$ and $j = 1,2,3, \ldots, n$ respectively.

Step 2: Calculate the average decision matrix by using equation (7) where k is the total respondents.

$$x_{ij} = \frac{1}{k}\sum_{t=1}^{k} x_{ij}^{t}, \qquad i = 1,2,3, \ldots, m;\ j = 1,2,3, \ldots, n. \tag{7}$$

Step 3: Normalise the decision matrix by equation (8).

$$f_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}},\ i = 1, \ldots, m; j = 1, \ldots, n. \tag{8}$$

Step 4: Determine the best f_j^* and the worst f_j^- values of all criterion functions $j = 1,2, \ldots, n$ as model (9). If the criterion j is a benefit, then:

$$f_j^* = \max_i x_{ij},$$
$$f_j^- = \min_i x_{ij}. \tag{9}$$

Step 5: Compute advantage, S_i and regret, R_i values $i = 1,2, \ldots m$ by the relations in (10) and (11).

$$S_i = \sum_{j=1}^{n} \frac{(f_j^* - x_{ij})}{(f_j^* - f_j^-)} \tag{10}$$

$$R_i = max\left[w_j \frac{(f_j^* - x_{ij})}{(f_j^* - f_j^-)}\right]. \tag{11}$$

Step 6: Compute VIKOR, $Q_i$values by the relations (12) to (16).

$$Q_i = v\frac{(S_i - S^*)}{S^- - S^*} + (1 - v)\frac{(R_i - R^*)}{R^- - R^*}, \tag{12}$$

$$S^* = \min_i S_i, \quad (13)$$

$$S^- = \max_i S_i, \quad (14)$$

$$R^* = \min_i R_i, \quad (15)$$

The solution generated by $\min_i S_i$ is with maximum group utility (or the majority rule) and the one obtained by $\min_i R_i$ is with a minimum regret of the opponent and v is introduced as a weight for the maximum group utility, which is v = 0.5, whereas $(1 - v)$ is the weight of the individual regret.

Step 7: Rank the alternatives, sorting them by the values S, R, and Q in ascending order.

Step 8: The alternatives were ranked based on the minimum Q_i if the following two conditions are satisfied:

Condition 1: Acceptable Advantage where the first rank alternative (A^1) is chosen if:

$Q(A^2) - Q(A^1) > \frac{1}{(m-1)}$ where A^2 is the alternative with the second position and m represents the total alternatives.

Condition 2: Acceptable stability in decision-making where first rank alternative (A^1) must also be the best ranked by S_i and or R_i values.

Sensitivity analysis is a useful method for testing the model's robustness and eliminating bias during data collecting and analysis (Kumar et al., 2020). Sensitivity analysis in VIKOR is used to examine how the ranking of the test kits varied when the criteria weights were adjusted.

RESULTS AND DISCUSSION

The ranking of preference in selecting RTK by 40 decision-makers was evaluated based on five criteria by BWM and six alternatives by the VIKOR method.

Weights of Criteria Using BWM

Each respondent indicated their choice for their best criterion over all other criteria (BO) and their preference for all criteria over their worst criterion (OW). The first decision maker

(DM1) was used to describe the BWM implementation. For instance, DM1 chooses usability (C_4) as the most significant criterion, while cost (C_1) is the least important based on the questionnaire in Part A. Table 3 shows the pairwise comparison of BO based on DM1 response to Part B for question 1. The usability criterion is three times more important than the cost, seven times more important than the sensitivity, five times more important than the advertising and seven times more important than the accessibility. The comparison between the usability and usability criterion is one since they are both equally significant.

Table 3: Pairwise Comparison of BO for DM1

Best to Others (BO)	Cost (C_1)	Sensitivity (C_2)	Advertising (C_3)	Usability (C_4)	Accessibility (C_5)
Usability (C_4)	3	7	5	1	7

The vector of the best criterion to others is written as (17).

$$A_B = (3 \quad 7 \quad 5 \quad 1 \quad 7). \tag{17}$$

Table 4 indicates the results of pairwise comparison of others to the worst based on DM1 response to Part B for question 2. The sensitivity, advertising, usability and accessibility criteria are four times more important than the cost.

Table 4: Pairwise Comparison of OW for DM1

Others to the Worst (OW)		Cost (C_1)
Cost	(C_1)	1
Sensitivity	(C_2)	4
Advertising	(C_3)	4
Usability	(C_4)	4
Accessibility	(C_5)	4

The vector of others to the worst is A_W as in (18).

$$A_W = (1 \quad 4 \quad 4 \quad 4 \quad 4)^T = \begin{pmatrix} 1 \\ 4 \\ 4 \\ 4 \\ 4 \end{pmatrix}. \tag{18}$$

The pairwise comparison is transferred into the min-max model as in (19).

$$
\begin{aligned}
&|w_4 - 3w_1| \leq \xi,\\
&|w_4 - 7w_2| \leq \xi,\\
&|w_4 - 5w_3| \leq \xi,\\
&|w_4 - 7w_5| \leq \xi,\\
&|w_2 - 4w_1| \leq \xi,\\
&|w_3 - 4w_1| \leq \xi,\\
&|w_4 - 4w_1| \leq \xi,\\
&|w_5 - 4w_1| \leq \xi,\\
&w_1 + w_2 + w_3 + w_4 + w_5 = 1,\\
&w_1, w_2, w_3, w_4, w_5 \geq 0.
\end{aligned}
\tag{19}
$$

where w_1, w_2, w_3, w_4, w_5 are weight of cost, sensitivity, advertising, usability, and accessibility respectively.

The data obtained from the survey was loaded into Microsoft Excel's Data Solver to calculate the optimal weight and ranking for each criterion. The optimal weight and ranking of each criterion for DM1 are shown in Table 5. DM1 believes that usability is more important than advertising, sensitivity, and accessibility. The least important criterion is cost.

Table 5: DM1 Preferred Criteria Weight

Best to Others (BO)	Cost (w_1)	Sensitivity (w_2)	Advertising (w_3)	Usability (w_4)	Accessibility (w_5)
Weight (w^*)	0.0915	0.1118	0.1565	0.5285	0.1118
Rank	5	3	2	1	3

The average weight of each decision-makers for criteria as shown in Table 6 is derived using arithmetic means by accumulating the decision makers' ratings based on the criteria of each alternative, then dividing by the number of decision-makers. Sensitivity is rated as the most important criterion, followed by usability, cost, accessibility, and advertising. For example, the average weight for cost is calculated as $\frac{8.8627}{40} = 0.2216$.

Table 6: Criteria Weightage and Rank of Decision Makers

	Cost	Sensitivity	Advertising	Usability	Accessibility
Total Weight	8.8627	10.4564	4.8201	9.0465	6.8143
Average Weight	0.2216	0.2614	0.1205	0.2262	0.1704
Rank	3	1	5	2	4

Validation for BWM results involves inconsistency analysis. The result for ξ shows the outcome's dependability based on the degree of consistency in the comparisons. The consistency index for comparison is calculated as in Equation (5). The total consistency for comparison, $\xi = 10.8717$. The average of the consistency index $= 0.2718$. The weight and rank acquired are highly reliable since the consistency index is near zero. Hence, the weight and rank acquired are highly reliable.

Ranking of Alternatives Using VIKOR

Six alternatives were ranked using the VIKOR approach. Table 8 shows the average decision matrix, where k is 40, the total number of respondents. For instance, the average decision for A1 and C1 is given by $\frac{127}{40} = 3.175$.

Table 7: Decision Makers' Matrix

	Cost	Sensitivity	Advertising	Usability	Accessibility
Alternatives	C1	C2	C3	C4	C5
A1	3.175	5.100	3.400	5.375	5.525
A2	5.925	5.425	3.375	5.600	5.475
A3	5.075	5.825	3.325	5.225	4.875
A4	6.175	6.550	3.375	6.050	5.175
A5	7.100	6.350	4.700	7.450	7.225
A6	6.350	6.625	3.625	6.675	6.000

Table 9 shows the normalised decision matrix elements fij = $\frac{x_{ij}}{\sqrt{\sum_{i=1}^{6} x_{ij}^2}}$. The calculation f_{11} for A1 and C1 element is shown by Equation (20).

$$f_{11} = \frac{x_{11}}{\sqrt{\sum_{i=1}^{6} x_{ij}^2}}$$

$$= \frac{3.175}{\sqrt{(3.175)^2 + (5.925)^2 + (5.075)^2 + (6.175)^2 + (7.1)^2 + (6.350)^2}} \quad (20)$$

$$= 0.2246$$

Table 8: Decision Makers' Normalised Matrix

	Cost	Sensitivity	Advertising	Usability	Accessibility
	C1	C2	C3	C4	C5
A1	0.2246	0.3466	0.3786	0.3590	0.3914
A2	0.4192	0.3687	0.3759	0.3740	0.3879
A3	0.3590	0.3959	0.3703	0.3489	0.3454
A4	0.4369	0.4452	0.3759	0.4040	0.3666
A5	0.5023	0.4316	0.5234	0.4975	0.5118
A6	0.4492	0.4503	0.4037	0.4458	0.4251

Table 10 presents the outcome calculation of normalised decision matrix to four decimal places in identifying the best and worst values. The best and worst values for each criterion by decision makers based on the advantage, S_i and regret, R_i and VIKOR, Q_i are in Table 11. The value of v = 0.5 has been applied. The Q values are arranged in ascending order.

Table 9: The Best and Worst Criteria for Decision Makers

	Cost	Sensitivity	Advertising	Usability	Accessibility
	C1	C2	C3	C4	C5
Best of amount, f_j^*	0.5023	0.4503	0.5234	0.4975	0.5118
Worst of amount, f_j^-	0.2246	0.3466	0.3703	0.3489	0.3454
$f_j^* - f_j^-$	0.2777	0.1036	0.1531	0.1486	0.1665

Table 10: Ranking Results for Decision Makers

	Si	Rank	Ri	Rank	Qi	Rank
A1	0.9311	6	0.2614	6	1	6
A2	0.7031	4	0.2057	4	0.7410	4
A3	0.7685	5	0.2262	5	0.8258	5
A4	0.4721	3	0.1486	3	0.4772	3
A5	0.0471	1	0.0471	1	0	1
A6	0.3041	2	0.0942	2	0.2552	2

The rank of the preferences for alternatives is $A_5 > A_6 > A_4 > A_2 > A_3 > A_1$. Product A_5 meets both conditions. For condition 1, that is $Q(A_6) - Q(A_5) = 0.2552$ is greater than 0.2,

that is $\left(\frac{1}{6-1}\right)$. For condition 2, A_5 is also ranked by S_i and R_i values as the most preferred brand.

For validation of the VIKOR method, sensitivity analysis is done. The value of the criteria was modified by utilising a low value ranging from 0 to 1. Value 0.2 indicates low, the value of 0.5 is intermediate, and the value of 0.8 represents high. Tables 12 and 13 show the VIKOR, Qi and ranking results based on different values of v. It depicts that the first rank is A_5. The v values and ranking results for v from 0 to 1 rank are not affected by the changes in weights. Hence, A_5 is most preferred by the decision makers compared to other RTK, given the maximum group utility and minimum individual regret. Similarly, A1 remains unchanged by the v value where this test kit is less preferred from the perspective of maximum group utility and minimum individual regret. The acquired results are reliable based on the consistency in the comparisons and the sensitivity analysis. The outcome of implementing BWM found that sensitivity is the most significant factor when purchasing RTK. As for the application of VIKOR, the results indicate that A_5 is the most preferred brand with a sensitivity of 91.38% and the lowest price, which is RM5.96.

Table 11: VIKOR, Qi Results

v	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
						Qi					
A1	1	1	1	1	1	1	1	1	1	1	1
A2	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
A3	0.84	0.83	0.83	0.83	0.83	0.83	0.82	0.82	0.82	0.82	0.82
A4	0.47	0.47	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
A5	0	0	0	0	0	0	0	0	0	0	0
A6	0.22	0.23	0.23	0.24	0.25	0.26	0.26	0.27	0.28	0.28	0.29

Table 12: Ranking Results Based on Different Values of v

v	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
						Rank					
A1	6	6	6	6	6	6	6	6	6	6	6
A2	4	4	4	4	4	4	4	4	4	4	4
A3	5	5	5	5	5	5	5	5	5	5	5
A4	3	3	3	3	3	3	3	3	3	3	3
A5	1	1	1	1	1	1	1	1	1	1	1
A6	2	2	2	2	2	2	2	2	2	2	2

CONCLUSION

Analysis on 40 ex-Covid patients and medical experts by implementing BWM found that sensitivity is the most significant factor followed by usability and cost. The sensitivity and accuracy of RTK is critical in determining the test result as positive or negative. Majority of the decision makers prefer saliva kit since it is easier to use compared to nasal especially for kids. Eventually, as in most product, cost is one of the concern factors since most of the time customers will buy RTK in bulk. Manufacturers of test kits can assess their capability and limitations based on respondents' evaluation of the products to enhance the demand and marketing. In addition, consumers can make reasonable decisions to purchase RTK based on their preference criteria based on result of this research.

Further research can be carried out using the proposed method in evaluating other types of test kits such as lollipop and whistling and other alternatives that are available on the market. Other than the five criteria (cost, accessibility, advertising, and practicality or usability) that might be considered in future research are packaging and word-or-mouth (recommendation by netizens). It is also suggested that other MCDM techniques such as Analytic Hierarchy Process can be used to compare the efficacy of the results.

REFERENCES

Abdulkareem, K. H., Arbaiy, N., & Zaidan, A. A. (2020). *A Novel Multi-Perspective Benchmarking Framework for Selecting Image Dehazing Intelligent Algorithms Based on BWM and Group VIKOR Techniques*. https://doi.org/10.1142/S0219622020500169

Aggregated Rapid Test Kit Supplier in Malaysia. https://rapidtestkit.com.my

Ahmadi, H. B., Kusi-Sarpong, S., & Rezaei, J. (2017). Assessing the social sustainability of supply chains using Best Worst Method. Resources, Conservation and Recycling, 126(July), 99–106. https://doi.org/10.1016/j.resconrec.2017.07.020

Anojkumar, L., Ilangkumaran, M., & Sasirekha, V. (2014). Comparative analysis of MCDM methods for pipe material selection in sugar industry. *Expert Systems with Applications*, 41(6), 2964–2980. https://doi.org/10.1016/j.eswa.2013.10.028

Çalik, A. (2020). Evaluation of social media platforms using Best-Worst method and fuzzy VIKOR methods: A case study of travel agency. *Iranian Journal of Management Studies*, 13(4), 645–672. https://doi.org/10.22059/IJMS.2020.294545.673893

Covid Test Kit from Watson Malaysia. https://www.watsons.com.my/blog/health-wellbeing/

Gupta, H. (2017). Evaluating service quality of airline industry using hybrid best worst method and VIKOR. *Journal of Air Transport Management*, 68, 35–47. https://doi.org/10.1016/j.jairtraman.2017.06.001

Khandker, S. S., Hashim, N. H. H. N., Deris, Z. Z., Shueb, R. H., & Islam, M. A. (2021). Diagnostic accuracy of rapid antigen test kits for detecting SARS-CoV-2: A systematic review and meta-analysis of 17,171 suspected COVID-19 patients. *Journal of Clinical Medicine*, 10(16). https://doi.org/10.3390/jcm10163493

Kumar, A., Aswin, A., & Gupta, H. (2020). Evaluating green performance of the airports using hybrid BWM and VIKOR methodology. *Tourism Management*, 76 (June 2019), 103941. https://doi.org/10.1016/j.tourman.2019.06.016

Leung, K. H., Lau, H. C. W., Nakandala, D., Kong, X. T. R., & Ho, G. T. S. (2020). Standardising fresh produce selection and grading process for improving quality assurance in perishable food supply chains: an integrated Fuzzy AHP-TOPSIS framework. *Enterprise Information Systems*, 1–25. https://doi.org/10.1080/17517575.2020.1790041

Lwin, C. Y. (2018). *Implementation of Decision Support System for choosing Pre-wedding Photo Service*. Master Dissertation, University of Computer Studies, Yangon.

Hamidah Maidinsah, Nurin Fatini Mustafa Kamal, & Nur Nadia Jafri, (2021). Preference In Selecting Home Broadband Plans Using Best-Worst Method. *International Journal of Economics, Commerce and Management*, Vol 9 (11), ISSN 234803.

Hirschmann, R. (2022). COVID-19 cases breakdown Malaysia 2022. Statista. https://www.statista.com/statistics/1103202/malaysia-covid-19-tested-cases-breakdown/

Kamal, M., Abo Omirah, M., Hussein, A., & Saeed, H. (2020). Assessment and characterisation of post-COVID-19 manifestations. *International Journal of Clinical Practice*, 75(3). https://doi.org/10.1111/ijcp.13746

Mak, G. C., Cheng, P. K., Lau, S. S., Wong, K. K., Lau, C. S., Lam, E. T., Chan, R. C., & Tsang, D. N. (2020). Evaluation of rapid antigen test for detection of SARS-CoV-2 virus. *Journal of Clinical Virology*, 129(June), 104500. https://doi.org/10.1016/j.jcv.2020.104500

Medical Device Authority (MDA) (2022). *Self-Test Covid-19 Test Kit for Conditional Approval* (Approved) - Medical Device Authority (MDA). Official Portal Medical Device Authority Ministry of Health Malaysia. https://www.mda.gov.my/announcement/631-self-test-covid-19-test-kit-for-conditional-approval-approved.html

Nadzira Amanina Mohamad (2020). *Application of Principal Component Analysis, Best Worst Method and Simple Additive Weighting for Consumer Preferences on Coffee Chains*. Unpublished Master Dissertation, University of Technology MARA, Shah Alam, Malaysia.

Opricovic, S., & Tzeng, G. H. (2004). Compromise solution by MCDM methods: A comparative analysis of VIKOR and TOPSIS. *European Journal of Operational Research*, 156(2), 445–455. https://doi.org/10.1016/S0377-2217(03)00020-1

Parhizgarsharif, A., Lork, A., & Telvari, A. (2019). A hybrid approach based on the BWM-VIKOR and GRA for ranking facility location in construction site layout for Mehr project in Tehran. *Decision Science Letters*, 8(3), 233–248. https://doi.org/10.5267/j.dsl.2019.3.001

Rafieyan, E., Khorsand, R., & Ramezanpour, M. (2020). An adaptive scheduling approach based on integrated best worst and VIKOR for cloud computing. *Computers & Industrial Engineering*, 140(July 2019), 106272. https://doi.org/10.1016/j.cie.2020.106272

Aggregated Rapid Test Kit Supplier in Malaysia. https://rapidtestkit.com.my

Rezaei, J., Wang, J., & Tavasszy, L. (2015). Linking supplier development to supplier segmentation using Best Worst Method. *Expert Systems with Applications*, 42(23), 9152–9164. https://doi.org/10.1016/j.eswa.2015.07.073

Syafiqah Salim (2021). Govt says Covid-19 RTK antigen self-test kits to be priced at no more than RM19.90 per unit from Sept 5. *The Edge Markets*. https://www.theedgemarkets.com/article/govt-sets-max-price-covid19-test-kits-under-rm20-unit-sept-5

World Health Organization (WHO). (2021). *Antigen-detection in the diagnosis of SARS-CoV-2 infection*. https://www.who.int/publications/i/item/antigen-detection-in-the-diagnosis-of-sars-cov-2infection-using-rapid-immunoassays

Wu, Q., Zhou, L., Chen, Y., & Chen, H. (2019). An integrated approach to green supplier selection based on the interval type-2 fuzzy best-worst and extended VIKOR methods. *Information Sciences*, 502, 394–417. https://doi.org/10.1016/j.ins.2019.06.049

Zhou, L., Li, Z., Zhou, J., Li, H., Chen, Y., Huang, Y., Xie, D., Zhao, L., Fan, M., Hashmi, S., Abdelkareem, F., Eiada, R., Xiao, X., Li, L., Qiu, Z., & Gao, X. (2020). A Rapid, Accurate and Machine-Agnostic Segmentation and Quantification Method for CT-Based COVID-19 Diagnosis. *IEEE Transactions on Medical Imaging*, 39(8), 2638–2652. https://doi.org/10.1109/TMI.2020.3001810.

APPENDIX

1) QUESTIONNAIRE: SELECTION OF COVID-19 RTK ANTIGEN SELF-TEST KIT

Tick (✓) for following questions:

Gender: ☐ Male ☐ Female

Participant: ☐ Ex-Covid-19 Patient ☐ Medical expert

PART A (Consumer's Criteria Preference)

There are five (5) criteria for selecting a Covid-19 RTK antigen self-test kit in this study as described:

Cost	The price of the Covid-19 RTK antigen self-test kit.
Sensitivity	The accuracy of Covid-19 RTK antigen self-test kit.
Advertising	The public notice about a product (cost, sensitivity & sampling type).
Practicality/Usability	Easy to use.
Accesibility	Easy to obtain in store.

Please tick (✓) one box only.

1. Which of the following criteria is the "**most important**" for choosing Covid-19 RTK antigen self-test kit?

☐ Cost
☐ Sensitivity
☐ Advertising
☐ Practicality/Usability
☐ Accessibility

2. Meanwhile, which criteria do you think is the "**least important**" in choosing Covid-19 RTK antigen self-test kit?

☐ Cost
☐ Sensitivity
☐ Advertising
☐ Practicality/Usability
☐ Accessibility

PART B (Pairwise Comparison)

Table 1: Rating scale for important preference

Numeric Values	Explanation
1	Equally important
3	Moderately more important
5	Strongly more important
7	Very strongly more important
9	Extremely more important
2,4,6,8	Use even numbers for intermediate judgment

This section will be based on answer in **Part A.**

1. **(answer question 1 Part A)** criterion is **(rating scale)** times more important than **(list of criteria in the question)**

Eg: If you choose "Cost" as the most important criteria thus, cost criterion is 7 times more important than accessibility

2. **(list of criteria in the question)** criterion is **(rating scale)** times more important than **(answer question 2 Part A)**

Eg: If you choose "Usability" as the least important criteria thus, sensitivity criterion is 5 times more important than usability

1. How much more important is the “most important criteria” compared to other criteria based on a discrete scale in Table 1?

Criteria	1	2	3	4	5	6	7	8	9
Cost									
Sensitivity									
Advertising									
Practicality/Usability									
Accessibility									

2. How much more important are other criteria compared to the “least important criteria” based on a discrete scale as in Table 1?

Criteria	1	2	3	4	5	6	7	8	9
Cost									
Sensitivity									
Advertisin									
Practicality/Usabilit									
Accessibility									

PART C (Consumer’s Alternatives Preference)

Covid-19 RTK antigen self-test kit (RTK) to be selected based on your preference and requirements as described:

Test Kit	**Sample Type**	**Sensitivity**	**Price**
RTK 1	Saliva and nasal swab	91.4%	RM19.90
RTK 2	Saliva and nasal swab	91.67%	RM6.90

RTK 3	Saliva and nasal swab	93.3%	RM8.50
RTK 4	Saliva	100%	RM6.90
RTK 5	Saliva	91.38%	RM5.96
RTK 6	Saliva	96.7%	RM6.90

How would you rank the following Covid-19 RTK antigen self-test kit (RTK) alternatives according to your preference in ascending order starting from 1 to 5? (1 refers to most preferred and 5 refers to least preferred)

RTK1	**RTK2**	**RTK3**	**RTK4**	**RTK5**	**RTK6**

Please tick (✓) only in **one** of the boxes based on your criteria preference for each RTK using the following scale:

Table 2: Rating Scale for alternatives preference

Numeric Values	**Explanation**
1	Not preferred at all
3	Moderately preferred
5	Strongly preferred
7	Very strongly preferred
9	Extremely preferred
2,4,6,8	Use even numbers for preference intermediate judgment

Example:

Tick (✓) only in **one** of the boxes based on your criteria preference for each RTK using scale in Table 2.

RTK: Brand A

Criteria	1	2	3	4	5	6	7	8	9
Cost						✓			
Sensitivity								✓	
Advertising	✓								
Practicality/Usability					✓				
Accessibility						✓			

RTK 1

Criteria	1	2	3	4	5	6	7	8	9
Cost									
Sensitivity									
Advertising									
Practicality/ Usability									
Accessibility									

RTK 2

Criteria	1	2	3	4	5	6	7	8	9
Cost									
Sensitivity									
Advertising									
Practicality/ Usability									
Accessibility									

RTK 3

Criteria	1	2	3	4	5	6	7	8	9
Cost									
Sensitivity									
Advertising									
Practicality/ Usability									
Accessibility									

RTK 4

Criteria	1	2	3	4	5	6	7	8	9
Cost									
Sensitivity									
Advertising									
Practicality/ Usability									
Accessibility									

RTK 5

Criteria	1	2	3	4	5	6	7	8	9
Cost									
Sensitivity									
Advertising									
Practicality/ Usability									
Accessibility									

RTK 6

Criteria	1	2	3	4	5	6	7	8	9
Cost									
Sensitivity									
Advertising									
Practicality/ Usability									
Accessibility									

THANK YOU FOR YOUR RESPONSE