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Evaluating Video Conferencing Software for Remote Working Using Two-Stage Grey MCDM: A Case Study from Vietnam

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Abstract: The COVID-19 pandemic has completely changed the world, and businesses are struggling to create a new and effective working environment for their employees. Employees worldwide have moved from traditional face-to-face meetings to remote working using video conferencing software (VCS)—a powerful tool to support companies during the pandemic and that can be an increasing trend in the future. For businesses who intend to adopt VCS for their organizations, choosing an appropriate platform can be an arduous task that requires the consideration of multiple criteria to save costs and optimize efficiency. In this paper, we propose a grey-based multi-criteria decision making (MCDM) framework that combines grey Analytical Hierarchy Process (G-AHP) and grey Evaluation Based on Distance from Average Solution (G-EDAS) methodologies, in which grey numbers are used to express the linguistic evaluation statements of experts. Initially, the evaluation criteria based on functionality, security, usability, technical performance, and pricing have been determined using a literature review and expert's opinions to employ the MCDM approach. G-AHP was utilized to identify the criteria weights, and G-EDAS was then used to select the best VCS among the alternatives. A case illustration in Vietnam is presented to exhibit the proposed approach's applicability. From the G-AHP findings, quality of video/audio, ease of use, mobile experience, number of participants allowed, and video recording capability have been ranked as the five most important criteria. From G-EDAS analysis, Microsoft Teams (VCS-03) was found to be the best. In addition, the robustness of the proposed model was tested by conducting sensitivity analysis and comparative analysis of methods, in which the priority rankings of the best VCSs are very similar. With the high demand for the trend of the remote working model, this study can be a basis for informed decisions to assist businesses in choosing their best-suited VCS to save costs and enhance productivity.

Keywords: video conferencing software; remote working; evaluation; multiple criteria decision-making; grey theory; G-AHP method; G-EDAS method

MSC: 62C05; 97U50; 68T35; 68T37; 00A71; 13P25

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1. Introduction

Since the COVID-19 pandemic began, working from home has become an increasing trend and can potentially replace the traditional style of working at the office. Before the pandemic hit in early 2020, telecommuting was not standard for businesses, and most people worked together in offices and communicated directly. During the lockdown, there has been a huge change in the way people live and work, especially causing the current work environment to change and improve online solutions. The practice of working from home or anywhere has become necessary and normalized these days. However, many people still face various shortcomings in arranging their workplace at home or are even uncomfortable with remote work. Therefore, a suitable and effective remote working model is today at the forefront of any business worldwide [1]. Software solutions and digital platforms with simple and intuitive usage for remote working are of vital importance in this direction.

Employing remote meeting support tools is a must to join any work team globally, and communication tools such as videoconferencing system tools are one such solution for companies and government organizations due to their ability to bridge the geographical gap between users and replace face-to-face meetings. While video conferencing software (VCS) has been widely used in many countries around the world, for Vietnam, many businesses have not yet implemented it. A main reason is the high investment cost, and more critical than that is the ingrained traditional meeting habits and cultures of organizations [2]. Otherwise, companies integrating VCS into their organization and using it from time to time may find it not effective or suitable for their business model when now half the workday or more is spent video conferencing. Aware of this, many market players, both domestic and international, are reaching out to enterprises and organizations to expand their services in the country [3]. With so many applications on the market, choosing the right VCS is the key to increasing employee productivity and efficiency, creating benefits for the business while maximizing value in total costs. The best platform must be considered and evaluated that suits each business's specific requirements based on a range of factors such as app functionality, technical performance, price, features, and security, to name a few [4]. Therefore, it can be assumed that choosing a suitable VCS is a complex multi-criteria decision-making problem (MCDM) that aims to reduce the initial selection of alternatives for a final decision in different aspects.

In this paper, we propose an MCDM-based framework with grey theory for the evaluation and determination of the best-suited VCS for businesses in Vietnam. When taking numerous aspects of the sector into the decision-making process, MCDM methods are efficient and practical tools for selection modeling to support experts and managers to weigh and balance numerous factors to simplify and clarify decisions. With this in mind, the standard catalogue for this assessment was initially defined, taking into account expert opinion and literature such as functionality (number of participants allowed, video feeds, application integration, smart meetings), security (malware attacks, face recognition attacks, confidentiality of personal data), usability (mobile experience, user interface, ease of use), technical performance (quality of video/audio, customer support, video recording capability), and pricing (cost of software/service, cost of equipment). We consider eight VCS that specialists in Vietnam recommend for the evaluation: Google Meet, Zoom, Microsoft Teams, Skype, and Facebook Room are international platforms, while TranS, VNPT Meeting, and Zalo are three platforms developed by domestic companies.

The grey-based model employed to conduct the study is an integration of the grey Analytical Hierarchy Process (G-AHP) and grey Evaluation Based on Distance from Average Solution (G-EDAS) and was used to examine the importance of each selected criterion and to prioritize platforms based on the final key criteria. The AHP method, which is widely used in MCDM, has been successfully applied to the ranking process of decision problems. The method's key benefits include its natural capacity to manage the intangibles present in any decision-making process and assist decision-makers in organizing the essential components of an issue in a hierarchical structure [5]. AHP can be integrated with well-known operation research techniques to solve increasingly challenging situations. The proposed EDAS methodology is an emerging MCDM method that benefits from simplicity in computing [6] and whose validity has been proven by Peng and Selvachandran [7] through comparison with other conventional methods, such as TOPSIS (technique for order of preference by similarity to ideal solution) [8], VIKOR (Visekriterijumska Optimizacija I Kompromisno Resenje) [9], TODIM (an acronym in Portuguese of interactive and multi-criteria decision making) [10], and several weighting algorithms. Thus, the hybrid MCDM methodology can be a good choice for practitioners to identify the critical factors as well as determine the best alternatives with our proposed case study.

Furthermore, in real-world applications and many actual settings, the selection is further complicated by uncertainty—an unavoidable feature due to the vagueness of human judgments and imprecise information. Unquantifiable, incomplete, and non-accessible information and partial ignorance are examples of imprecise sources, and experts may be hesitant or unable to assign accurate numerical values to comparison judgments [11]. In this direction, the two major methodologies for incorporating uncertainty and ambiguity into the evaluation process are fuzzy sets theory [12] and grey systems theory [13]. Crisp or conventional approaches are less effective in dealing with imprecision or vagueness, whereas fuzzy sets theory and grey systems theory provide a useful paradigm for analyzing systems with imprecise data and successfully handling uncertainty. While most studies have used a fuzzy sets approach to manage uncertainty in evaluation, totally grey theory has not been developed with the MCDM techniques used in this research area. The method is compared to the well-proven fuzzy MCDM methods, where reaching the results can justify applying the grey-based MCDM. One advantage of the grey set over the fuzzy sets is the simplified calculation method and the ability to provide more reliable results [14]. Thus, one of our study's purposes is to demonstrate the applicability of grey-based multi-criteria models other than fuzzy MCDM techniques to choose the best VCS, in which the grey approach can also eliminate the vagueness of experts' judgments. Uncertain ratings, represented by grey numbers, can also generate more accurate and robust rankings for alternatives.

Our research contributions can be summarized as follows. (1) In practice, this is the first study to conduct a thorough evaluation of VCS for businesses in Vietnam, which provides a significant guideline for managers and practitioners. A comprehensive set of factors considered while assessing the alternatives is a significant advantage of the proposed work. (2) Methodologically, this is the first attempt to consider the merits of grey theory, AHP, and EDAS methodologies in the existing literature of VCS evaluation. (3) For managerial implications, our proposed approach and results can be a basis for informed decisions, which would be helpful for businesses to save costs and enhance productivity, especially those struggling in the new working style in the COVID-era or those intending to adopt VCS for their organizations. The method can be useful for other similar industries.

The rest of the paper is organized as follows. In Section 2, a literature review on VCS evaluation, relevant criteria, and proposed MCDM methods is given. Section 3 primarily explains the methodologies applied to the case study attempted in this work. A case illustration is covered in Section 4, whereas sensitivity analysis and comparative analysis are conducted to check the robustness of the proposed model in Section 5. Section 6 includes concluding remarks as well as recommendations for future study.

2. Literature Review

2.1. Literature on VCS Evaluation and Relevant Criteria

Since the onset of the COVID-19 pandemic is also when companies began to apply VCS to their business models, the evaluation of VCS has received great attention from many scholars. Zou et al. (2020) [15] stated that higher education communities worldwide have moved from traditional face-to-face teaching to remote learning by using VCS and other online learning applications with the COVID-19 pandemic. The authors tried to determine the most user-friendly and the best-suited VCS for online classes by proposing the usability heuristics to evaluate the major video conferencing platforms (e.g., Cisco Webex, Microsoft Teams, and Zoom), considering more than 10 hypotheses in their assessment. Xu et al. (2021) [16] performed a VCS selection where the criterion values were expressed in mathematical representations that might alter with natural epidemic conditions. The entire VCS selection procedure was carried out with approaches for processing and normalizing the multi-format evaluation values. Cavus and Sekyere-Asiedu (2021) [17] compared VCS and concluded their implications to education during the COVID-19 pandemic. The authors utilized a comparative research method to compare Microsoft Teams, Google Meet, Cisco WebEx Meetings, GoToMeeting, ClickMeetings, Zoom Meetings, and BigBlueButton under these criteria: features, archive meeting, meeting duration, trial versions, account creation to use and mobility, security, maximum participants meeting recording duration, and chat/screen sharing.

Çakır and Ulukan (2021) [18] proposed interval-valued fuzzy parameterized intuitionistic fuzzy soft sets for VCS selection in a case in Turkey. Ten alternatives were evaluated under these criteria: performance and capability, file and screen sharing, online meeting quality and recording, implementation, security, and support system. Mary and Merlin (2021) [19] developed a unified technique that was created using an interval-valued intuitionistic fuzzy cognitive map (IVIFCM) for investigating VCS (i.e., Zoom, Google Meet, Microsoft Teams, and Institutional LMS) used in teaching and learning during COVID-19 in India; five criteria were considered: exclusive features or conferencing features, web features, simple and streamlined, pricing and user friendliness, and security. Qayyum et al. (2021) [20] presented the feature-based selection for open-source VCS systems using fuzzy AHP. The alternatives evaluated were Blue Jeans, GoToMeeting, Team Viewer, Join.me, Zoom, and UberConference under these criteria: ease of use, effective communication, special functions and features, performance efficiency, security, portability, support, and their 21 sub-criteria. Menekşe and Camgöz Akdağ (2022) [21] proposed the AHP and EDAS methodologies under a spherical fuzzy sets environment to compare and contrast five prominent videoconferencing technologies, namely Zoom, Google Meet, Cisco WebEx, Skype, and Microsoft, based on six criteria (technical performance, functionality, usability, security, privacy, and cost), which were further divided into 32 sub-categories.

2.2. Literature Review on Methodology

The Analytic Hierarchy Process (AHP) was developed by Saaty [22] and is a powerful MCDM technique that has many advantages. The method enables evaluation, ranking, and criteria selection, which results in optimized and predicted decisions. It is one of the most popular selection modeling techniques for software platforms. For example, Lai et al. [23] used the AHP method to support the selection of a multi-media authorizing system (MAS) in a group decision environment. Zaidan et al. [24] evaluated and selected the best software among 13 active open-source EMR software packages in the healthcare area based on an integrated AHP and TOPSIS analysis. Employing the fuzzy AHP and grey TOPSIS methodologies to minimize any ambiguity and greyness in the decision-making, Li and Sun [25] determined the most significant factors for designing a successful e-commerce website, and from that, the best website was chosen by using the finalized key factors. Besides fuzzy AHP, the grey theory method is proven to be effective and can be applied to any scientific problem when there is incomplete or inaccurate information [26]. The efficiency of the technique is compared to stochastic probability and fuzzy mathematics; researchers concluded that the grey approach is well suited to variable weight clustering. Bu et al. [27] used the grey AHP method to evaluate crime prevention systems to guarantee the accuracy of the weight coefficients. Sahoo et al. [28] employed the grey AHP in environmental management policies selection. They indicated that the grey theory application helped to eliminate the dependency on the experience of experts. Baradaran [29] combined AHP with grey system theory to reduce uncertainty and incomplete information in evaluating incidents in urban railway systems, obtaining results with lower computational complexity. To overcome the limitations of the uncertainty in the classical AHP method, Alkharabsheh et al. [30] presented a grey AHP model to facilitate the public transport system's supply quality evaluation. Toan et al. [31] proposed an integrated approach of grey AHP and grey TOPSIS for the selection of online education platforms.

The Evaluation based on Distance from Average Solution (EDAS) is a novel and efficient method proposed in 2015 by Keshavarz Ghorabaee et al. [6] to solve inventory classification. Since then, the approach has been widely used in multiple areas due to its efficiency and simple calculation, generating consistent results with other MCDM approaches. For example, Trinkūnienė et al. [32] used the EDAS method for the evaluation of quality assurance in different contractor contracts. Turskis and Juodagalvienė [33] employed EDAS with many other MCDM methods to assess the shape of stairs for dwelling houses; similarly, Zavadskas et al. [34] proposed methods for the assessment of a safe and healthy built environment in Vilnius that follows sustainable development principles through a practical neighborhood-based approach. Hou et al. [35] proposed the EDAS method with improvements for the safety risk assessment of metro construction under epistemic uncertainty. EDAS was extended with fuzzy sets theory and applied to the supplier selection problem in 2016 [36] and for the selection of solid waste disposal sites in 2017 [37]. Stanujkic et al. [38] presented a grey extension of the EDAS method and since then, this hybrid method has been used in many other real-world MCDM problems. For instance, Kaviani et al. [39] proposed an integrated multi-criteria decision-making approach with the grey EDAS methodology for supplier evaluation and selection in the oil and gas industry. Jain et al. [40] proposed a grey–entropy–EDAS model to determine the best resilience-based strategies for hotel and tourism supply chain against the COVID-19 pandemic.

This paper demonstrates the effective application of both above-mentioned methods in the selection of complex VCSs under multiple criteria. The main theoretical and practical contributions of this paper lie in two areas. Firstly, the integration of G-AHP and G-EDAS methods was first proposed in the existing literature, at least in the domain of VCS evaluation and selection, in order to display the applicability and consider the merits of grey theory, AHP, and EDAS simultaneously. The combination of the methods can be considered as one innovation of our studies, as the existing literature has only shown the hybrid fuzzy AHP and fuzzy EDAS approaches [21,41–43]. Secondly, while most VCS selection studies, as previously discussed, are focused on the context of education, our unique and comprehensive review of the literature resulted in practical insights into the perspective of businesses in a sustainable manner, especially in the Vietnamese context, on the importance of selecting the best VCS to maximize productivity while saving costs and resources.

3. Materials and Methods

This paper proposes a two-stage grey AHP–EDAS MCDM model for evaluating video conferencing software with a case study in Vietnam. First, grey AHP is applied to calculate the grey weights of criteria. Then, grey EDAS is used to rank the alternatives. The sensitivity analysis of the appraisal score of grey EDAS and the comparison of methods are used to test the proposed model. Figure 1 shows the research framework used in this paper.

3.1. Grey Theory

Grey theory is one of the methods used to handle uncertainty, especially in MCDM problems [44]. In this paper, a combined grey AHP–EDAS method is proposed for evaluating video conferencing software with a case study on the top eight software companies in Vietnam. According to the grey theory, the information degree is divided into three categories—“black system”, “white system”, and “grey system”—based on whether the information is “unknown”, “completely known”, or “partially known”. The framework of the grey system theory is depicted in Figure 2.

Let $\otimes x$ be a grey number; the interval grey number is denoted by $\otimes x = [\underline{x}, \overline{x}]$ where $\underline{x}$ and $\overline{x}$ are the lower bound and the upper bound of the grey number. The grey number of an interval is a set of numbers whose exact amounts are unknown, but the interval ranges within which it falls are known. Let $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ be two grey numbers, k be a positive real number, and L be the length of grey numbers. The basic operations of the interval grey numbers $\otimes x_1$ and $\otimes x_2$ are defined as follows, as can be seen in Equations (1)–(6):

$$\otimes x_1 + \otimes x_2 = [\underline{x}_1 + \underline{x}_2, \overline{x}_1 + \overline{x}_2] \quad (1)$$

$$\otimes x_1 - \otimes x_2 = [\underline{x}_1 - \overline{x}_2, \overline{x}_1 - \underline{x}_2] \quad (2)$$

$$\otimes x_1 * \otimes x_2 = [min\ (\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2), max(\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2)] \quad (3)$$

$$\otimes x_1 / \otimes x_2 = [min\ (\underline{x}_1/\underline{x}_2, \underline{x}_1/\overline{x}_2, \overline{x}_1/\underline{x}_2, \overline{x}_1/\overline{x}_2), max(\underline{x}_1/\underline{x}_2, \underline{x}_1/\overline{x}_2, \overline{x}_1/\underline{x}_2, \overline{x}_1/\overline{x}_2)] \quad (4)$$

$$k \otimes x_1 = k[\underline{x}_1, \overline{x}_1] = [k\underline{x}_1, k\overline{x}_1] \quad (5)$$

$$L(\otimes x_1) = [\overline{x}_1 - \underline{x}_1] \quad (6)$$

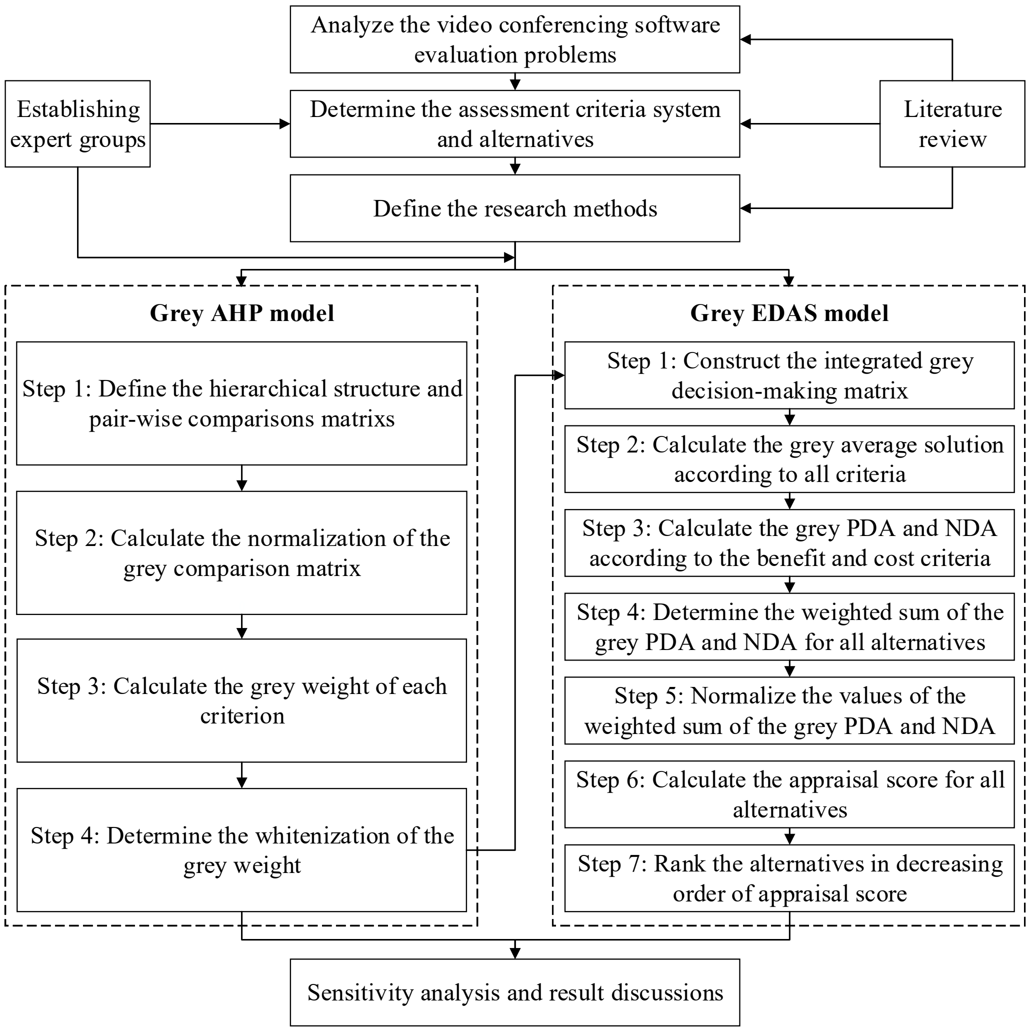

Figure 1. The proposed research framework used in this paper.

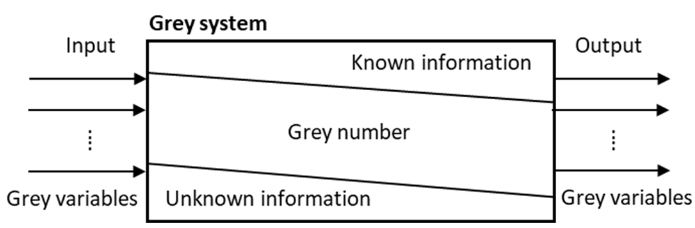

Figure 2. The framework of grey system theory.

3.2. Grey Analytical Hierarchy Process (G-AHP)

The grey Analytical Hierarchy Process (G-AHP) integrates AHP and grey theory to overcome the limitations of the uncertainty in the classical AHP model [45]. This paper used AHP based on the grey number scores to estimate the grey weights of criteria (i.e., the significant level of criteria). The process of G-AHP calculation is explained step-by-step as follows [46].

Step 1: Defining the hierarchical structure of the complex decision problem using experts' evaluation with grey numbers. The linguistic scale with grey numbers used in the G-AHP model is presented in Table 1. Then, the integrated grey comparison matrix is developed using geometrical integration, as can be seen in Equation (7).

$$D = \begin{bmatrix} \otimes x_{11} & \cdots & \otimes x_{1n} \\ \vdots & \vdots & \vdots \\ \otimes x_{m1} & \cdots & \otimes x_{mn} \end{bmatrix} = \begin{bmatrix} [\underline{x}_{11}, \overline{x}_{11}] & \cdots & [\underline{x}_{1n}, \overline{x}_{1n}] \\ \vdots & \vdots & \vdots \\ [\underline{x}_{m1}, \overline{x}_{m1}] & \cdots & [\underline{x}_{mn}, \overline{x}_{mn}] \end{bmatrix} \tag{7}$$

Table 1. The linguistic scales used in G-AHP.

Importance Value	Linguistics Scales	Grey Numbers $[\underline{x}, \overline{x}]$
1	Equivalent importance (EI)	[1, 2]
3	Medium importance (MI)	[2, 4]
5	Strong importance (SI)	[4, 6]
7	Very Strong importance (VSI)	[6, 8]
9	Extreme importance (EMI)	[8, 10]

Step 2: Calculating the normalization of the grey comparison matrix using Equations (8)–(10).

$$D^* = \begin{bmatrix} \otimes x^*_{11} & \cdots & \otimes x^*_{1n} \\ \vdots & \vdots & \vdots \\ \otimes x^*_{m1} & \cdots & \otimes x^*_{mn} \end{bmatrix} = \begin{bmatrix} [\underline{x}^*_{11}, \overline{x}^*_{11}] & \cdots & [\underline{x}^*_{1n}, \overline{x}^*_{1n}] \\ \vdots & \vdots & \vdots \\ [\underline{x}^*_{m1}, \overline{x}^*_{m1}] & \cdots & [\underline{x}^*_{mn}, \overline{x}^*_{mn}] \end{bmatrix} \tag{8}$$

$$\underline{x}^*_{ij} = \frac{\underline{x}_{ij}}{\frac{1}{2}\left(\sum_{i=1}^{m} \underline{x}_{ij} + \sum_{i=1}^{m} \overline{x}_{ij}\right)} = \frac{2\underline{x}_{ij}}{\sum_{i=1}^{m} \underline{x}_{ij} + \sum_{i=1}^{m} \overline{x}_{ij}} \tag{9}$$

$$\overline{x}^*_{ij} = \frac{\overline{x}_{ij}}{\frac{1}{2}\left(\sum_{i=1}^{m} \underline{x}_{ij} + \sum_{i=1}^{m} \overline{x}_{ij}\right)} = \frac{2\overline{x}_{ij}}{\sum_{i=1}^{m} \underline{x}_{ij} + \sum_{i=1}^{m} \overline{x}_{ij}} \tag{10}$$

where $\otimes x_{ij}$ is the value of assessment given by the decision-makers for the i-th criterion over the j-th criterion.

Step 3: Calculating the grey weight of each criterion from the normalized grey comparison matrix, as in Equation (11).

$$\otimes w_i = \frac{\sum_{j=1}^{n} \otimes x^*_{ij}}{n} \tag{11}$$

where $n = \{1, 2, \ldots, N\}$ is the set of criteria.

Step 4: Calculating the whitenization of the grey weight of each criterion using Equation (12). The whited value of the interval grey weight is a crisp number whose potential value is between the lower bound and upper bound of the interval grey weight.

$$M_i = (1 - \lambda)\underline{w}_i + \lambda \overline{w}_i \tag{12}$$

where λ is the whitening coefficient, and $\lambda \in [0, 1]$.

3.3. Grey Evaluation Based on Distance from Average Solution (G-EDAS)

Evaluation based on Distance from Average Solution (EDAS) was introduced by Ghorabaee et al. [36]. The concept of EDAS is based on two distance measures, which are the positive distance from average (PDA) and negative distance from average (NDA). In a decision-making problem, the optimal alternative is selected according to a higher value of the PDA and lower value of the NDA.

Stanujkic et al. [38] first introduced grey Evaluation based on Distance from Average Solution (GEDAS) to reduce the subjective judgments using grey numbers in an evaluation process. The process of G-EDAS calculation is explained step-by-step as follows.

Step 1: Construct the integrated grey decision-making matrix. Suppose that $A = \{A_1, A_2, \ldots, A_m\}$ is a discrete set of m *alternatives*, which are evaluated by a discrete set $C = \{C_1, C_2, \ldots, C_n\}$ of n criteria.

The performance ratings of the alternatives with respect to criteria are conducted using the linguistic scale with grey numbers in Table 2. Assume that there are k experts, and the value of the grey number $\otimes X_{ij}$ of the alternative i with respect to the criterion j is calculated using Equation (13). Then, the integrated grey decision matrix is constructed in Equation (14).

$$\otimes X_{ij} = \frac{1}{k}\left(\otimes X_{ij}^1 + \otimes X_{ij}^2 + \ldots + \otimes X_{ij}^k\right) \tag{13}$$

$$\otimes X = \begin{bmatrix} \otimes X_{11} & \otimes X_{12} & \cdots & \otimes X_{1n} \\ \otimes X_{21} & \otimes X_{22} & \cdots & \otimes X_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \otimes X_{m1} & \otimes X_{m2} & \cdots & X_{mn} \end{bmatrix} \tag{14}$$

where $\otimes X_{ij} = \left[\underline{X}_{ij}, \overline{X}_{ij}\right]$ is the grey numbers of the performance ratings of the alternative i with respect to the criterion j.

Table 2. The linguistics scales used in G-EDAS.

Linguistics Scales	**Grey Numbers [$\underline{X}$, $\overline{X}$]**
Very Poor (VP)	[0, 1]
Poor (P)	[1, 3]
Medium Poor (MP)	[3, 4]
Fair (F)	[4, 5]
Medium Good (MG)	[5, 6]
Good (G)	[6, 9]
Very Good (VG)	[9, 10]

Step 2: Calculate the grey average solution according to all criteria using Equations (15)–(17).

$$\otimes X_j^* = \left(\left[\underline{X}_1^*, \overline{X}_1^*\right], \left[\underline{X}_2^*, \overline{X}_2^*\right], \ldots, \left[\underline{X}_n^*, \overline{X}_n^*\right]\right) \tag{15}$$

$$\underline{X}_j^* = \frac{\sum_{i=1}^m \underline{X}_{ij}}{m} \tag{16}$$

$$\overline{X}_j^* = \frac{\sum_{i=1}^m \overline{X}_{ij}}{m} \tag{17}$$

Step 3: Calculate the grey positive distance from average (PDA) $\otimes d_{ij}^+ = \left[\underline{d}_{ij}^+, \overline{d}_{ij}^+\right]$ and the grey negative distance from average (NDA) $\otimes d_{ij}^- = \left[\underline{d}_{ij}^-, \overline{d}_{ij}^-\right]$ according to the benefit and cost criteria.

The lower bound $\underline{d}_{ij}^+$ and the upper bound $\overline{d}_{ij}^+$ bound of the grey PDA can be determined by Equations (18) and (19).

$$\underline{d}_{ij}^+ = \begin{cases} \frac{max\left(0, \left(\underline{X}_{ij} - \overline{X}_j^*\right)\right)}{0.5\left(\underline{X}_j^* + \overline{X}_j^*\right)}; j \in \theta_{max} \\ \frac{max\left(0, \left(\underline{X}_j^* - \overline{X}_{ij}\right)\right)}{0.5\left(\underline{X}_j^* + \overline{X}_j^*\right)}; j \in \theta_{min} \end{cases} \tag{18}$$

$$\overline{d}_{ij}^{+} = \begin{cases} \frac{max\left(0,\left(\overline{X}_{ij}-\underline{X}_{j}^{*}\right)\right)}{0.5\left(\underline{X}_{j}^{*}+\overline{X}_{j}^{*}\right)}; j \in \theta_{max} \\ \frac{max\left(0,\left(\overline{X}_{j}^{*}-\underline{X}_{ij}\right)\right)}{0.5\left(\underline{X}_{j}^{*}+\overline{X}_{j}^{*}\right)}; j \in \theta_{min} \end{cases} \tag{19}$$

where θ_{max} and θ_{min} are the sets of the benefit criteria and the cost criteria, respectively.

Similarly, the lower $\underline{d}_{ij}^{-}$ and the upper $\overline{d}_{ij}^{-}$ bound of the grey NDA can be determined by Equations (20) and (21).

$$\underline{d}_{ij}^{-} = \begin{cases} \frac{max\left(0,\left(\underline{X}_{j}^{*}-\overline{X}_{ij}\right)\right)}{0.5\left(\underline{X}_{j}^{*}+\overline{X}_{j}^{*}\right)}; j \in \theta_{max} \\ \frac{max\left(0,\left(\underline{X}_{ij}-\overline{X}_{j}^{*}\right)\right)}{0.5\left(\underline{X}_{j}^{*}+\overline{X}_{j}^{*}\right)}; j \in \theta_{min} \end{cases} \tag{20}$$

$$\overline{d}_{ij}^{-} = \begin{cases} \frac{max\left(0,\left(\overline{X}_{j}^{*}-\underline{X}_{ij}\right)\right)}{0.5\left(\underline{X}_{j}^{*}+\overline{X}_{j}^{*}\right)}; j \in \theta_{max} \\ \frac{max\left(0,\left(\overline{X}_{ij}-\underline{X}_{j}^{*}\right)\right)}{0.5\left(\underline{X}_{j}^{*}+\overline{X}_{j}^{*}\right)}; j \in \theta_{min} \end{cases} \tag{21}$$

where θ_{max} and θ_{min} are the sets of the benefit criteria and the cost criteria, respectively.

Step 4: Determine the weighted sum of the grey PDA $\otimes Q_i^{+} = \left[\underline{Q}_i^{+}, \overline{Q}_i^{+}\right]$ and the weighted sum of the grey NDA $\otimes Q_i^{-} = \left[\underline{Q}_i^{-}, \overline{Q}_i^{-}\right]$ for all alternatives using Equations (22)–(25).

$$\underline{Q}_i^{+} = \sum_{j=1}^{n} w_j \underline{d}_{ij}^{+} \tag{22}$$

$$\overline{Q}_i^{+} = \sum_{j=1}^{n} w_j \overline{d}_{ij}^{+} \tag{23}$$

$$\underline{Q}_i^{-} = \sum_{j=1}^{n} w_j \underline{d}_{ij}^{-} \tag{24}$$

$$\overline{Q}_i^{-} = \sum_{j=1}^{n} w_j \overline{d}_{ij}^{-} \tag{25}$$

where w_j is the grey weight of each criterion, which is calculated from the G-AHP model.

Step 5: Normalize the values of the weighted sum of the grey PDA $S_i^{+} = \left[\underline{S}_i^{+}, \overline{S}_i^{+}\right]$ and the weighted sum of the grey NDA $\otimes S_i^{-} = \left[\underline{S}_i^{-}, \overline{S}_i^{-}\right]$ for all alternatives using Equations (26)–(29).

$$\underline{S}_i^{+} = \frac{\underline{Q}_i^{+}}{\max\limits_k \overline{Q}_k^{+}} \tag{26}$$

$$\overline{S}_i^{+} = \frac{\overline{Q}_i^{+}}{\max\limits_k \overline{Q}_k^{+}} \tag{27}$$

$$\underline{S}_i^{-} = 1 - \frac{\overline{Q}_i^{-}}{\max\limits_k \overline{Q}_k^{-}} \tag{28}$$

$$\overline{S}_i^{-} = 1 - \frac{\underline{Q}_i^{-}}{\max\limits_k \overline{Q}_k^{-}} \tag{29}$$

Step 6: Calculate the appraisal score S_i for all alternatives using Equation (30).

$$S_i = \frac{1}{2}\left[(1-\alpha)\left(\underline{S}_i^- + \underline{S}_i^+\right) + \alpha\left(\overline{S}_i^- + \overline{S}_i^+\right)\right] \quad (30)$$

where α is the coefficient value of the G-EDAS model if decision-makers want to assign different weights to the lower and upper bounds of the grey interval. In this paper, the value of α is considered as 0.5 ($\alpha = 0.5$) for beginning analysis.

Step 7: Rank the alternatives in decreasing order of appraisal score. Among the candidate alternatives, the alternative with the highest S_i is the best decision.

4. Results

4.1. A Case Study in Vietnam

To analyze the practicality of the new integrated approach of G-AHP and G-EDAS methods introduced in this paper, the above-mentioned issue of choosing the best-suited VCS for businesses is considered. The alternatives are Google Meet (VCS-01), Zoom (VCS-02), Microsoft Teams (VCS-03), Skype (VCS-04), TranS (VCS-05), VNPT Meeting (VCS-06), Zalo (VCS-07), and Facebook Room (VCS-08), as can be seen in Table 3. A summary of these alternatives is presented as follows. Google Meet is a web-based videoconferencing tool provided by the Google company (Ho Chi Minh City, Vietnam). Zoom is a software platform that allows for face-to-face meetings and delivers video, audio, and message services for global distance communication. Microsoft Teams is a video conferencing and talking platform. Skype online meeting software is released by Microsoft. The main users are organizations and units that conduct online video conferencing meetings. This software works with various smart devices and can scale up to 250 people. VNPT Meeting is a product of Vietnam Posts and Telecommunications Group (VNPT) in cooperation with Polycom. This is a cloud-based video meeting solution. VNPT Meeting makes it easy for organizations to conduct online meetings anywhere and on any PC, laptop, or mobile device such as smartphones and tablets with an internet connection. The service allows multiple people to attend online meetings at different locations simultaneously. TranS is released by Namviet Telecom Company (Ho Chi Minh City, Vietnam). This online learning and meeting application allows video chats anytime, anywhere. TranS is a useful tool that is widely used in education and helps businesses connect online quickly. Zalo is an application that allows free texting and calling on mobile and computer platforms used by many users. Zalo is researched, developed, and published by VinaGame Company (VNG), Vietnam. To meet the needs of online meetings during the pandemic, Zalo has launched a new feature that allows online sessions for groups of many people simultaneously. Online VCS via Facebook Room is implemented based on the application platform released by Facebook, allowing up to 50 people to join a meeting simultaneously on many different types of devices.

Table 3. The list of video conferencing software companies used in this study.

No	Symbol	Software Name
1	VCS-01	Google Meet
2	VSC-02	Zoom
3	VCS-03	Microsoft Teams
4	VCS-04	Skype
5	VSC-05	TranS
6	VCS-06	VNPT Meeting
7	VCS-07	Zalo
8	VSC-08	Facebook Room

The alternatives are evaluated with respect to 4 main dimensions and 15 criteria, as shown in Table 4. The hierarchical tree for the evaluation of the video conferencing software is presented in Figure 3. For the evaluation of criteria and alternatives, software specialists and experts were invited and requested to give their opinions. A panel of 15 experts with professional experience with respect to software and business experience was asked, and by identifying alternative measures and critical evaluation criteria, the results were made as objective as possible. Many vital considerations such as consumer behaviors, tools or support teams to integrate products with a business, or many more market-related matters were referenced and discussed between experts and specialists to determine critical factors for evaluating and selecting alternatives for businesses. After discussions, the evaluation indicator system was constructed and finalized as the suitable and comprehensive set of criteria responsible for the feasible implementation of the VCS from a developing country's perspective.

Table 4. The list of criteria used in this study.

Dimension	Criteria	Attribute
Functionality (C1)	C11. Number of participants allowed	Benefit
	C12. Video feeds	Benefit
	C13. Application integration	Benefit
	C14. Smart meetings	Benefit
Security (C2)	C21. Malware attacks	Cost
	C22. Face recognition attacks	Cost
	C23. Confidentiality of personal data	Benefit
Usability (C3)	C31. Mobile experience	Benefit
	C32. User interface	Benefit
	C33. Ease of use	Benefit
Technical Performance (C4)	C41. Quality of video/audio	Benefit
	C42. Customer support	Benefit
	C43. Video recording capability	Benefit
Pricing (C5)	C51. Cost of software/service	Cost
	C52. Cost of equipment	Cost

4.2. Calculation of Grey Weights with G-AHP

In this section, G-AHP is applied to compute the grey weight of the evaluation criteria for the evaluation and selection of the video conferencing software with a case study in Vietnam. A total of five dimensions are considered, including environmental functionality (C1), security (C2), usability (C3), technical performance (C4), and pricing (C5), which are decomposed into 15 criteria.

The following procedure shows how to calculate the weight of the eigenvector of five dimensions and the process of the consistency ratio calculation. The initial comparison matrix with grey numbers of G-AHP is shown in Table 5 below.

Table 5. The initial comparison matrix of G-AHP.

Dimension	Left Criteria Is Greater					Right Criteria Is Greater				Dimension
	EMI	VSI	SI	MI	EI	MI	SI	VSI	EMI	
C1			1	1	1	5	5	2		C2
C1			2	1	4	5	3			C3
C1			2	2	3	4	4			C4
C1			2	6	6	1				C5
C2			3	5	4	3				C3
C2				2	4	4	5			C4
C2		6	5	3	1					C5
C3			1	3	2	4	5			C4
C3	1	3	5	6						C5
C4		6	6	2	1					C5

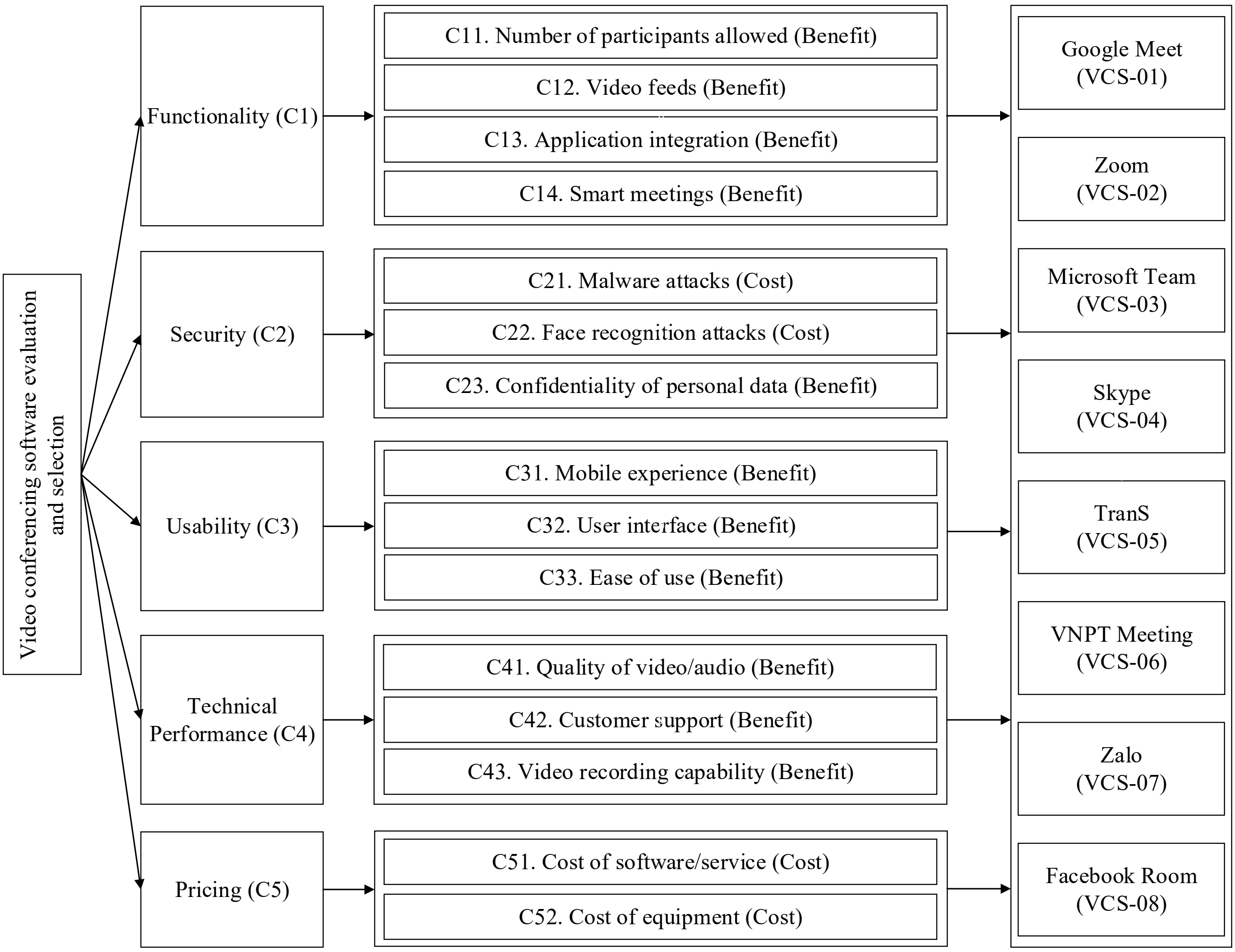

Figure 3. The hierarchical tree for evaluation of video conferencing software.

The grey number is transformed to a crisp number to check the consistency ratio (*CR*) of the performance rating from experts' opinions. The crisp matrix of five dimensions is shown in Table 6.

Table 6. The crisp matrix of G-AHP.

Dimension	Functionality (C1)	Security (C2)	Usability (C3)	Technical Performance (C4)	Pricing (C5)
Functionality (C1)	1.000	0.375	0.670	0.697	1.787
Security (C2)	2.669	1.000	1.597	0.505	4.639
Usability (C3)	1.492	0.626	1.000	0.605	4.534
Technical Performance (C4)	1.435	1.980	1.653	1.000	4.800
Pricing (C5)	0.559	0.216	0.221	0.208	1.000
Total	7.155	4.196	5.141	3.015	16.761

Using a matrix calculator, divide each value in a column by the sum of the column values to obtain the normalized matrix of G-AHP. As shown in Table 7, the priority vector is constructed by averaging the row elements in the normalized matrix.

Table 7. The normalized matrix of G-AHP.

Dimension	Functionality (C1)	Security (C2)	Usability (C3)	Technical Performance (C4)	Pricing (C5)	Priority Vector
Functionality (C1)	0.140	0.089	0.130	0.231	0.107	0.139
Security (C2)	0.373	0.238	0.311	0.168	0.277	0.273
Usability (C3)	0.209	0.149	0.195	0.201	0.271	0.205
Technical Performance (C4)	0.201	0.472	0.321	0.332	0.286	0.322
Pricing (C5)	0.078	0.051	0.043	0.069	0.060	0.060
Total	1.000	1.000	1.000	1.000	1.000	1.000

The largest eigenvector (λ_{max}) is calculated to determine the consistency index (CI), the random index (RI), and the consistency ratio (CR), as below.

$$\begin{bmatrix} 1.000 & 0.375 & 0.670 & 0.697 & 1.787 \\ 2.699 & 1.000 & 1.597 & 0.505 & 4.639 \\ 1.492 & 0.626 & 1.000 & 0.605 & 4.534 \\ 1.435 & 1.980 & 1.653 & 1.000 & 4.800 \\ 0.599 & 0.216 & 0.221 & 0.208 & 1.000 \end{bmatrix} \times \begin{bmatrix} 0.139 \\ 0.273 \\ 0.205 \\ 0.322 \\ 0.060 \end{bmatrix} = \begin{bmatrix} 0.711 \\ 1.415 \\ 1.052 \\ 1.691 \\ 0.309 \end{bmatrix};$$

$$\begin{bmatrix} 0.711 \\ 1.415 \\ 1.052 \\ 1.691 \\ 0.309 \end{bmatrix} / \begin{bmatrix} 0.139 \\ 0.273 \\ 0.205 \\ 0.322 \\ 0.060 \end{bmatrix} = \begin{bmatrix} 5.102 \\ 5.177 \\ 5.140 \\ 5.245 \\ 5.137 \end{bmatrix}$$

In this paper, a total of five main criteria is considered. Hence, we get $n = 5$. Consequently, λ_{max} and CI are computed as below.

$$\lambda_{max} = \frac{5.102 + 5.177 + 5.140 + 5.245 + 5.137}{5} = 5.160$$

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{5.160 - 5}{5 - 1} = 0.040$$

such that $n = 5$, we get $RI = 1.12$, and the consistency ratio (CR) is computed as follows.

$$CR = \frac{CI}{RI} = \frac{0.040}{1.12} = 0.036$$

As shown in $CR = 0.036 < 0.1$, the result was satisfactory, and the pairwise comparison matrix was consistent. The same procedure is used to determine 15 criteria. Table A1 shows the integrated grey comparison matrix of the 15 criteria (Appendix A).

As the results from the G-AHP calculation, the grey weights and their transformed crisps are shown in Table 8. For example, for the grey weight of criteria C11, the number of participants allowed has the lowest weight (lower bound) at 0.060 and the highest weight (upper bound) at 0.104. Similar to this procedure, for the grey weight of criteria C12, video feeds has the lowest weight at 0.038 and the highest weight of 0.068. The significance levels of 15 criteria of the G-AHP model are displayed in Figure 4. The results indicate that the five most significant criteria are C41, quality of video/audio; C33, ease of use; C31, mobile experience; C11, number of participants allowed; and C43, video recording capability, with significance levels of 11.04%, 9.51%, 9.30%, 8.17%, and 7.43%, respectively. Meanwhile, C42, customer support, is specified as the least significant criterion, with a value of 3.75% compared to other considered criteria. The findings suggest that decision makers focus on "C41", "C33", "C31", "C1", and "C43" for improving the performance of the video conferencing software.

Table 8. The grey weights of G-AHP.

Criteria	Attribute	Grey Weights [$\underline{x}$, $\overline{x}$]		Crisp Weights
C11. Number of participants allowed	Benefit	0.060	0.104	0.082
C12. Video feeds	Benefit	0.038	0.068	0.053
C13. Application integration	Benefit	0.044	0.078	0.061
C14. Smart meetings	Benefit	0.033	0.059	0.046
C21. Malware attacks	Cost	0.043	0.075	0.059
C22. Face recognition attacks	Cost	0.036	0.063	0.049
C23. Confidentiality of personal data	Benefit	0.047	0.082	0.065
C31. Mobile experience	Benefit	0.068	0.118	0.093
C32. User interface	Benefit	0.047	0.081	0.064
C33. Ease of use	Benefit	0.070	0.120	0.095
C41. Quality of video/audio	Benefit	0.081	0.139	0.110
C42. Customer support	Benefit	0.027	0.048	0.038
C43. Video recording capability	Benefit	0.053	0.096	0.074
C51. Cost of software/service	Cost	0.049	0.086	0.067
C52. Cost of equipment	Cost	0.032	0.056	0.044

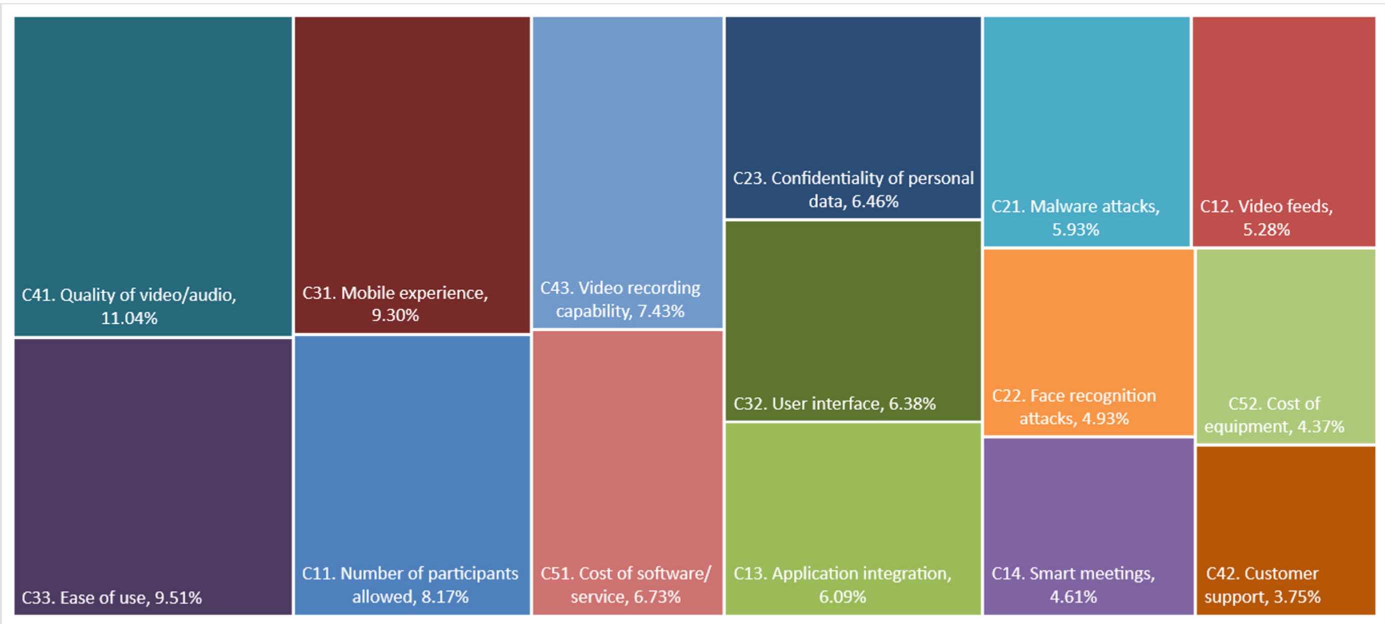

Figure 4. The significant level of criteria of G-AHP.

4.3. Ranking Alternatives with G-EDAS

In this step, G-EDAS was used to rank the alternatives. The preference grey weight of each criterion was obtained from the G-AHP model. According to the process of G-EDAS, the integrated grey decision matrix of alternative concerning criteria is presented in Table A2 (Appendix A). The evaluation of the appraisal score of the G-EDAS model is shown in Table 9. From the result, Microsoft Teams (VCS-03) achieves the highest performance with the appraisal score of 0.684. Zalo (VCS-07), with the appraisal score of 0.605, ranks second, and VNPT Meeting (VCS-06) ranks third with the appraisal score of 0.603. Meanwhile, TransS (VSC-05) has the lowest performance, with the appraisal score of 0.319. The ranking performance is visualized in Figure 5.

Table 9. The appraisal score S_i of G-EDAS.

Symbol	Software Name	$\underline{Q}_i^+$	$\overline{Q}_i^+$	$\underline{S}_i^+$	$\overline{S}_i^+$	$\underline{Q}_i^-$	$\overline{Q}_i^-$	$\underline{S}_i^-$	$\overline{S}_i^-$	S_i	Ranking
VCS-01	Google Meet	0.000	0.478	0.000	0.788	0.009	0.331	0.550	0.988	0.582	4
VSC-02	Zoom	0.000	0.379	0.000	0.625	0.000	0.396	0.462	1.000	0.522	6
VCS-03	Microsoft Teams	0.019	0.606	0.031	1.000	0.000	0.218	0.704	1.000	0.684	1
VCS-04	Skype	0.006	0.231	0.009	0.381	0.034	0.594	0.193	0.954	0.385	7
VSC-05	TranS	0.020	0.209	0.033	0.344	0.074	0.737	0.000	0.900	0.319	8
VCS-06	VNPT Meeting	0.009	0.497	0.015	0.820	0.000	0.311	0.577	1.000	0.603	3
VCS-07	Zalo	0.004	0.508	0.007	0.839	0.009	0.305	0.586	0.988	0.605	2
VSC-08	Facebook Room	0.005	0.453	0.008	0.748	0.004	0.352	0.523	0.995	0.568	5

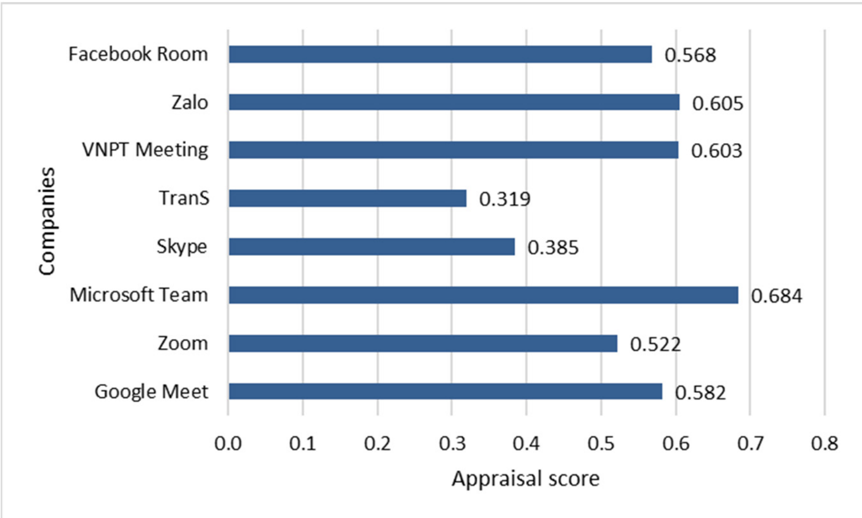

Figure 5. Final alternatives ranking of G-EDAS.

5. Results Validation

5.1. Sensitivity Analysis

A sensitivity analysis was performed to establish the robustness and stability of the proposed MCDM model [47]. The sensitivity analysis of the preference coefficient (i.e., the threshold value of the EDAS model, α) was conducted to validate the ranking order [48]. In a previous relevant study, the value of α was considered to be 0.5 ($\alpha = 0.5$) for base case analysis. However, this setting does not reflect the actual scenario in which various decision-makers have different preferences. Hence, in this paper, the preference coefficient of the EDAS model fluctuates in the range of ($\alpha = 0, 0.1, \ldots, 1$), as shown in Table 10. The change result is visualized in Figure 6. The ranking result shows that the optimal video conferencing software companies are always the same when changing the values of coefficient preference (α) from 0 to 1. It can be concluded that Microsoft Teams (VCS-03) is consistently the optimal video conferencing software company to use. Following that, Zalo (VCS-07) and VNPT Meeting (VCS-06) are also ranked second and third positions, which are also more suitable alternatives among other candidates. The applicability and robustness of the proposed MCDM model are demonstrated. Decision-maker psychology should be considered when making decisions in determining the optimal video conferencing software companies from multiple choice.

Table 10. The fluctuation coefficient value of G-EDAS.

Symbol	Software Name	Coefficient Values (α)										
		0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
VCS-01	Google Meet	0.275	0.336	0.398	0.459	0.520	0.582	0.643	0.704	0.766	0.827	0.888
VSC-02	Zoom	0.231	0.289	0.347	0.405	0.464	0.522	0.580	0.638	0.696	0.754	0.812
VCS-03	Microsoft Teams	0.367	0.430	0.494	0.557	0.620	0.684	0.747	0.810	0.873	0.937	1.000
VCS-04	Skype	0.101	0.158	0.215	0.271	0.328	0.385	0.441	0.498	0.554	0.611	0.668
VSC-05	TranS	0.016	0.077	0.137	0.198	0.259	0.319	0.380	0.440	0.501	0.561	0.622
VCS-06	VNPT Meeting	0.296	0.357	0.419	0.480	0.542	0.603	0.664	0.726	0.787	0.848	0.910
VCS-07	Zalo	0.296	0.358	0.420	0.481	0.543	0.605	0.667	0.728	0.790	0.852	0.914
VSC-08	Facebook Room	0.265	0.326	0.387	0.447	0.508	0.568	0.629	0.690	0.750	0.811	0.871

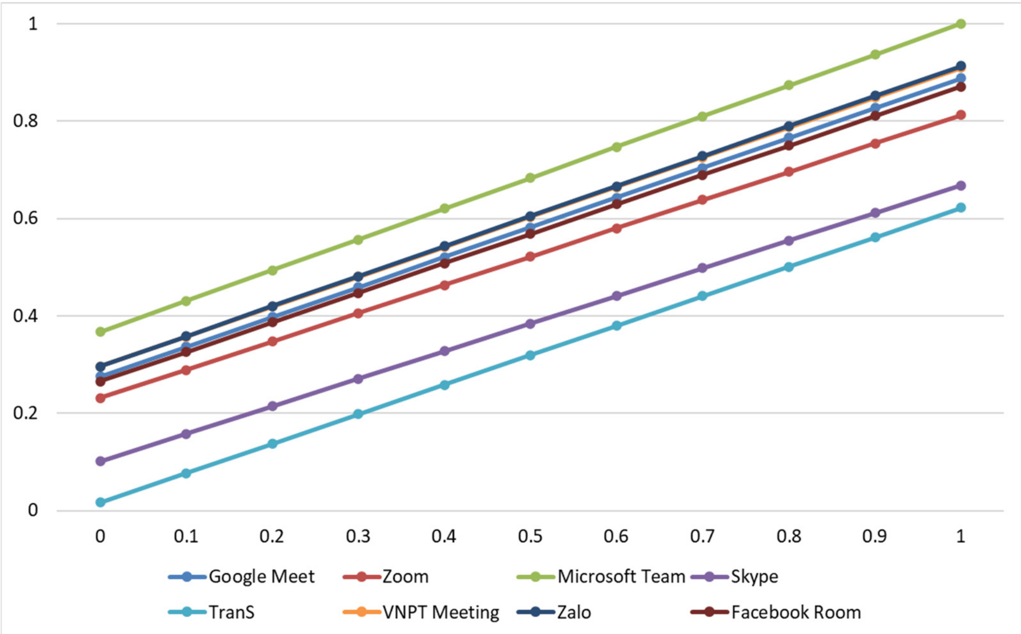

Figure 6. Sensitivity analysis of coefficient value of G-EDAS.

5.2. Comparative Analysis

Besides the sensitivity analysis of criteria, a comparative analysis among MCDM methods is conducted to demonstrate the rationale of the proposed model. In this section, three MCDM methods based on the use of interval grey numbers including the operational competitiveness rating (G-OCRA) [49], the complex proportional assessment (G-COPRAS) [50], and the technique for order of preference by similarity to ideal solution (G-TOPSIS) [51] models are utilized to rank the video software companies, which are compared to the G-EDAS method. The final ranking results of the compared methods are shown in Table 11 and also visualized in Figure 7. Based on the comparative findings, the rating of the video conferencing software companies with a case study in Vietnam during the COVID-19 pandemic is slightly changed; for example, VNPT Meeting (VCS-06) ranked at second position in the G-OCRA method but it ranked at third position in the G-COPRAS method, and Zalo (VCS-07) ranked third in the G-TOPSIS method but it ranked at second position in the G-COPRAS method—otherwise, it was ranked at the same ranking. In general, the ranking curve is rather smooth, indicating that the proposed MCDM (G-AHP and G-EDAS) ranking result is stable and applicable. Therefore, this work can be a useful decision-making framework for evaluating video conferencing software companies and related industries.

Table 11. Ranking of compared methods.

Symbol	Software Name	G-AHP G-EDAS		G-AHP G-OCRA		G-AHP G-COPRAS		G-AHP G-TOPSIS	
		Value	Rank	Value	Rank	Value	Rank	Value	Rank
VCS-01	Google Meet	0.582	4	0.582	4	0.915	4	0.684	4
VSC-02	Zoom	0.522	6	0.486	6	0.854	6	0.725	6
VCS-03	Microsoft Teams	0.684	1	0.739	1	1.000	1	0.641	1
VCS-04	Skype	0.385	7	0.221	7	0.733	7	0.803	7
VSC-05	TranS	0.319	8	0.000	8	0.702	8	0.830	8
VCS-06	VNPT Meeting	0.603	3	0.639	2	0.926	3	0.669	2
VCS-07	Zalo	0.605	2	0.628	3	0.935	2	0.674	3
VSC-08	Facebook Room	0.568	5	0.504	5	0.899	5	0.714	5

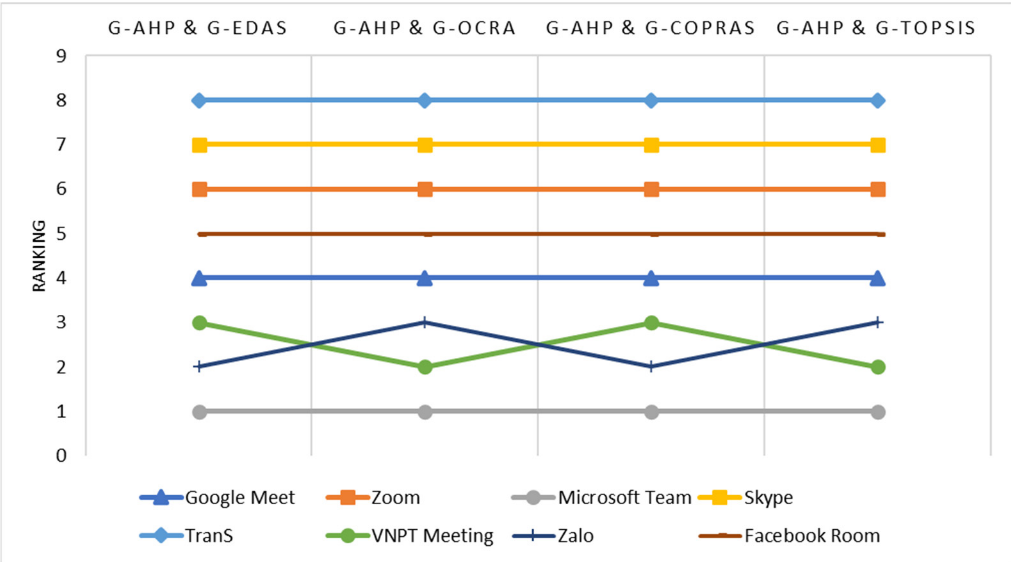

Figure 7. Comparative analysis of methods.

6. Research Implications

This study has several beneficial implications for both software adopters and developers, as well as academicians, as follows.

For managers who intend to adopt VCS for their business, this study reveals some challenges in evaluating and selecting the right VCS, which has managerial implications for managers to support their businesses while saving costs and resources. Especially for a developing country like Vietnam, where the working tradition has always been oriented towards face-to-face meetings, companies now have difficulty in transitioning to remote working in response to the current situation. In developing VCS selection criteria and evaluating the effectiveness of the selection process, there are important criteria and dimensions of criteria that have been identified. A complete understanding of these criteria and dimensions will help to manage the challenges or barriers encountered.

From the academic point of view, this study presents an integrated approach based on G-AHP and G-EDAS for VCS selection with minimal or no quantitative data. Expert committees and grey theory are particularly well-suited to addressing the difficulty of evaluating sustainability practices while minimizing the effects of imprecise or missing data. G-AHP successfully provided consistent criteria ratings, whereas G-EDAS generates alternative rankings based on distance measures. The sensitivity and comparative analysis will allow practitioners to test the observation stability.

For software developers in the field, this study may provide a scientific means for managers who provide their video conferencing services to determine their strengths and weaknesses to improve their platform. This study's important benefit is the development of evaluation criteria using the literature and expert feedback that developers and stakeholders can utilize as a significant guideline.

7. Conclusions and Future Studies

Because of the COVID-19 epidemic, employees all over the world have shifted from traditional face-to-face meetings to remote working via VCS, online tools, and platforms. With social distancing requirements, VCS is projected to be part of the delivery modes at least until an effective vaccination becomes widely accessible. Even after the pandemic is over, it is expected that remote working through via these platforms will be part of the new or next normal. In this paper, an effective method for VCS selection with prominence on critical criteria has been established. The proposed approach enables the determination of the weights of the evaluation criteria by G-AHP and then to rank the alternatives by G-EDAS. Evaluation criteria that have obtained maximum weight priority in the analysis are quality of video/audio, ease of use, mobile experience, number of participants allowed, and video recording capability. Our final ranking indicates that Microsoft Teams (VCS-03) is the best VCS among alternatives. Sensitivity analysis and comparative analysis were conducted to test our model's robustness, with the results illustrating that the applied methods reach common VCS rankings. This shows that the proposed approach is practical in nature.

The main achievements and contributions of this work are as follows. First, this study is the first attempt to evaluate and rank the VCS for businesses in the context of Vietnam, which has never been reported in the existing literature. A comprehensive set of criteria is determined to assess the alternatives through a literature review and experts' opinions, which is a significant advantage of this work. Methodologically, the combination of G-AHP and G-EDAS is proposed for the first time to solve the problem that has been identified as appropriate and effective methodologies for VCS evaluation. For managerial implications, all selected evaluation criteria and experts' assessments presented in this research can be a basis for informed decisions for managers and decision-makers of any type of business. With a case study in Vietnam solved, managers of companies can utilize our approach and the obtained results to select the appropriate VCS for their organization. This will result in significant resource and cost savings as well as enhance the productivity of employees, especially in the context of the pandemic. The prescribed model can also be useful for other countries and related industries.

Although the methodology adopted in this study has been conducted successfully in terms of prioritizing different alternatives and factors, it is not without some limitations. One limitation can be the use of the AHP method. Although the consistency check in the present study has been fulfilled, it is inconceivable to neglect the inconsistency in the pairwise comparison matrix that might occur in practice for other problems. The Best–Worst Method (BWM) can overcome this drawback as it unburdens decision-makers by requiring fewer pairwise comparisons than the conventional AHP procedure, or the multi-level Parsimonious Analytic Hierarchy Process (PAHP) model can reduce survey duration significantly. The analytic network process (ANP) method can also be a better option to avoid the interrelationship of factors. Hence, these methods are recommended for future studies. Another limitation is that the evaluation process of VCS relies on the participation of specialists; as a result, findings are reliant on human opinions, expertise, and judgment. To get around this restriction, 15 specialists were enlisted to propose various choices. Other multi-criteria assessment procedures, such as VIKOR, TOPSIS, TODIM, COPRAS, WASPAS, and MOORA, might be used to accomplish the same purpose, and the results could be compared. Researchers are recommended to address these limitations in future work. The proposed methodology in this study can also be extended within the dynamic and uncertain environment in future research by integrating novel criteria factors, especially those regarding the current crisis. It could also be applied to different decision-making scenarios in various industries and countries with other multi-criteria methods as outlined earlier to see if the findings are generalizable.

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Appendix A

Table A1. The integrated grey comparison matrix of G-AHP.

Criteria	C11		C12		C13		C14		C21	
	$\underline{x}$	$\overline{x}$	$\underline{x}$	$\overline{x}$	$\underline{x}$	$\overline{x}$	$\underline{x}$	$\overline{x}$	$\underline{x}$	$\overline{x}$
C11. Number of participants allowed	1.000	1.000	1.203	2.272	2.316	4.063	1.118	2.111	0.803	1.431
C12. Video feeds	0.440	0.831	1.000	1.000	0.803	1.431	0.420	0.773	0.502	0.894
C13. Application integration	0.246	0.432	0.699	1.246	1.000	1.000	1.516	2.808	0.520	0.929
C14. Smart meetings	0.474	0.894	1.294	2.379	0.356	0.660	1.000	1.000	0.428	0.773
C21. Malware attacks	0.699	1.246	1.118	1.993	1.076	1.925	1.294	2.334	1.000	1.000
C22. Face recognition attacks	0.686	1.270	0.544	1.027	0.376	0.704	1.320	2.398	0.642	1.236
C23. Confidentiality of personal data	0.570	1.000	0.630	1.260	0.349	0.613	0.613	1.203	1.447	2.511
C31. Mobile experience	0.673	1.270	1.294	2.334	1.203	2.228	1.631	2.850	1.097	1.977
C32. User interface	0.496	0.894	0.366	0.673	0.630	1.260	1.171	2.128	1.631	2.884
C33. Ease of use	1.631	2.850	1.294	2.379	1.320	2.262	1.294	2.334	0.787	1.431
C41. Quality of video/audio	1.631	2.721	1.631	2.850	1.631	2.721	2.016	3.428	1.320	2.444
C42. Customer support	0.349	0.642	0.809	1.499	0.699	1.246	0.630	1.260	0.349	0.642
C43. Video recording capability	0.686	1.294	1.294	2.334	0.630	1.260	1.127	2.071	1.356	2.491
C51. Cost of software/service	0.520	1.000	0.630	1.260	1.260	2.228	0.912	1.708	1.180	2.211
C52. Cost of equipment	0.224	0.383	0.912	1.644	0.440	0.831	0.602	1.203	0.496	0.912

Criteria	C22		C23		C31		C32		C33	
C11. Number of participants allowed	0.787	1.459	1.000	1.755	0.787	1.487	1.118	2.016	0.351	0.613
C12. Video feeds	0.973	1.838	0.794	1.587	0.428	0.773	1.487	2.733	0.420	0.773
C13. Application integration	1.420	2.660	1.631	2.862	0.449	0.831	0.794	1.587	0.442	0.758
C14. Smart meetings	0.417	0.758	0.831	1.631	0.351	0.613	0.470	0.854	0.428	0.773
C21. Malware attacks	0.809	1.557	0.398	0.691	0.506	0.912	0.347	0.613	0.699	1.270
C22. Face recognition attacks	1.000	1.000	0.263	0.440	0.305	0.520	0.732	1.330	0.334	0.581
C23. Confidentiality of personal data	2.272	3.806	1.000	1.000	0.356	0.625	0.506	0.887	0.351	0.613
C31. Mobile experience	1.925	3.273	1.600	2.808	1.000	1.000	1.447	2.560	0.809	1.557
C32. User interface	0.752	1.366	1.127	1.977	0.391	0.691	1.000	1.000	0.417	0.758
C33. Ease of use	1.721	2.997	1.631	2.850	0.642	1.236	1.320	2.398	1.000	1.000
C41. Quality of video/audio	0.955	1.721	1.127	2.016	1.047	1.977	1.019	1.852	1.516	2.754
C42. Customer support	0.506	0.912	0.492	0.871	0.349	0.608	0.340	0.581	0.253	0.440
C43. Video recording capability	1.356	2.334	0.630	1.260	0.630	1.260	1.260	2.289	0.724	1.447
C51. Cost of software/service	1.068	1.940	0.724	1.420	0.440	0.831	1.330	2.379	0.383	0.724
C52. Cost of equipment	0.565	0.989	0.253	0.440	0.322	0.570	0.246	0.420	0.320	0.520

Criteria	C41		C42		C43		C51		C52	
C11. Number of participants allowed	0.368	0.613	1.557	2.862	0.773	1.459	1.000	1.925	2.609	4.457
C12. Video feeds	0.351	0.613	0.667	1.236	0.428	0.773	0.794	1.587	0.608	1.097
C13. Application integration	0.368	0.613	0.803	1.431	0.794	1.587	0.449	0.794	1.203	2.272
C14. Smart meetings	0.292	0.496	0.794	1.587	0.483	0.887	0.585	1.097	0.831	1.662
C21. Malware attacks	0.409	0.758	1.557	2.862	0.401	0.738	0.452	0.847	1.097	2.016
C22. Face recognition attacks	0.581	1.047	1.097	1.977	0.428	0.738	0.515	0.937	1.011	1.769
C23. Confidentiality of personal data	0.496	0.887	1.149	2.032	0.794	1.587	0.704	1.382	2.272	3.955
C31. Mobile experience	0.506	0.955	1.644	2.862	0.794	1.587	1.203	2.272	1.755	3.101
C32. User interface	0.540	0.981	1.721	2.940	0.437	0.794	0.420	0.752	2.379	4.063
C33. Ease of use	0.363	0.660	2.272	3.955	0.691	1.382	1.382	2.609	1.925	3.126
C41. Quality of video/audio	1.000	1.000	1.925	3.378	1.068	1.977	1.789	3.225	1.097	2.016
C42. Customer support	0.296	0.520	1.000	1.000	0.520	0.929	0.351	0.613	0.555	1.047
C43. Video recording capability	0.506	0.937	1.076	1.925	1.000	1.000	0.673	1.320	1.320	2.379
C51. Cost of software/service	0.310	0.559	1.631	2.850	0.673	1.320	1.000	1.000	1.789	3.042
C52. Cost of equipment	0.496	0.912	0.955	1.803	1.320	2.379	0.329	0.559	1.000	1.000

Table A2. The integrated grey decision matrix of G-EDAS.

Criteria	**C11**		**C12**		**C13**		**C14**		**C21**	
	$\underline{X}$	$\overline{X}$	$\underline{X}$	$\overline{X}$	$\underline{X}$	$\overline{X}$	$\underline{X}$	$\overline{X}$	$\underline{X}$	$\overline{X}$
VCS-01	3.533	4.667	4.400	5.800	4.867	6.533	3.733	4.933	5.000	6.400
VSC-02	3.800	4.933	3.200	4.333	4.267	5.933	3.267	4.400	3.533	4.733
VCS-03	3.800	4.933	4.333	5.667	4.133	5.400	5.733	7.133	3.533	4.733
VCS-04	2.867	4.067	2.400	3.467	2.000	3.333	2.467	3.800	1.800	3.133
VSC-05	1.933	3.133	1.733	3.000	1.867	3.533	1.600	2.800	1.800	3.200
VCS-06	4.267	5.533	4.667	6.067	3.933	5.267	6.133	7.667	4.533	5.933
VCS-07	4.333	5.600	4.467	5.867	4.600	6.133	3.600	4.667	4.200	5.867
VSC-08	3.333	4.533	2.467	3.733	1.933	3.267	2.933	4.267	5.267	6.667
Criteria	C22		C23		C31		C32		C33	
VCS-01	2.867	4.067	3.733	4.800	4.533	6.067	5.267	6.667	4.800	6.467
VSC-02	4.000	5.333	3.867	5.267	3.200	4.533	4.067	5.400	2.600	3.800
VCS-03	2.867	4.067	3.733	4.800	4.533	6.067	5.267	6.667	4.800	6.467
VCS-04	2.200	3.267	1.867	3.133	3.200	4.533	2.267	3.333	1.000	2.400
VSC-05	1.667	3.000	1.400	2.800	1.467	2.867	1.867	3.133	2.333	3.533
VCS-06	2.600	4.000	3.467	4.667	4.600	6.133	3.600	4.667	4.200	5.867
VCS-07	3.333	4.533	3.733	5.000	4.467	5.867	5.667	7.067	5.267	6.667
VSC-08	3.533	4.800	4.733	6.133	5.600	7.000	4.400	5.800	5.000	6.533
Criteria	C41		C42		C43		C51		C52	
VCS-01	4.267	5.533	4.667	6.067	3.933	5.267	6.133	7.667	4.533	5.933
VSC-02	4.333	5.600	4.467	5.867	4.600	6.133	3.600	4.667	4.200	5.867
VCS-03	6.067	7.867	4.400	5.800	3.200	4.533	3.733	4.933	3.800	5.000
VCS-04	2.800	3.867	3.200	4.333	4.267	5.933	3.267	4.400	3.533	4.733
VSC-05	1.867	3.400	1.400	2.800	2.067	3.200	1.800	3.067	1.733	3.000
VCS-06	4.000	5.333	3.867	5.267	3.200	4.533	4.067	5.400	2.600	3.800
VCS-07	4.267	5.533	4.667	6.067	3.933	5.267	6.133	7.667	4.533	5.933
VSC-08	4.333	5.600	4.467	5.867	4.600	6.133	3.600	4.667	4.200	5.867

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