*Sensors and Materials*, Vol. 37, No. 8 (2025) 3679–3695
MYU Tokyo


S & M 4145

# Evaluating Nanyin Promotion Effectiveness – An Integrated Framework Using IoT, Delphi Method, and Fuzzy Analytic Hierarchy Process

Hui Zhou,[1] Xu Cui,[2*] Hui-Chen Tsai,[3] and Cheng-Fu Yang[4,5**]

[1]School of Music and Dance, Quanzhou Normal University, Quanzhou 362000, China
[2]Art College, Xiamen University, Xiamen 361005, China
[3]Center for General Education, Taiwan Steel University of Science and Technology, Kaohsiung 821, Taiwan
[4]Department of Chemical and Materials Engineering, National University of Kaohsiung, Kaohsiung 811, Taiwan
[5]Department of Aeronautical Engineering, Chaoyang University of Technology, Taichung 413, Taiwan

(Received June 5, 2025; accepted July 18, 2025)

***Keywords:*** UNESCO's representative list of Intangible Cultural Heritage of Humanity, Nanyin framework system, Delphi method, fuzzy analytic hierarchy process, Internet of Things

Nanyin (southern music of Fujian Province of China) was selected as one of the first entries in China's National Intangible Cultural Heritage List in 2006, and in 2009, it was included in the Representative List of United Nations Educational, Scientific and Cultural Organization (UNESCO) of the Intangible Cultural Heritage of Humanity. In this study, we constructed a scientifically sound evaluation framework for assessing the dissemination effectiveness of Nanyin by combining the Delphi method with the fuzzy analytic hierarchy process (Fuzzy-AHP). We first developed IoT technology to facilitate the transmission of related music and the collection and analysis of data. Next, we employed the Delphi method to gather expert opinions and identify key evaluation criteria. Subsequently, Fuzzy-AHP was used to quantify the weights of these criteria, creating a comprehensive and systematic evaluation model. The model includes five primary indicators: diversity and coverage of dissemination channels, content quality, media exposure, audience engagement, and audience satisfaction, along with their corresponding secondary indicators. To validate the practical application of this framework, we conducted an empirical analysis using the program "Hundred Birds Returning to the Nest" as a case study. IoT technology was employed to collect and disseminate relevant data, facilitating the analysis through the Delphi method and Fuzzy-AHP. The results showed that the developed evaluation framework effectively provides reliable data support and guidance for future Nanyin dissemination strategies.

## 1. Introduction

Nanyin, a traditional music form from Quanzhou, Fujian Province, was listed as China's National Intangible Cultural Heritage in 2006 and added to the Representative List of United

*Corresponding author: e-mail: cuixu@xmu.edu.cn
**Corresponding author: cfyang@nuk.edu.tw
https://doi.org/10.18494/SAM5791

ISSN 0914-4935 © MYU K.K.
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Nations Educational, Scientific and Cultural Organization (UNESCO) in 2009. Blending literature, music, and performance, its graceful melodies are cherished in southern Fujian, Taiwan, and Southeast Asia. Nanyin is a key symbol of Minnan culture and Chinese music heritage. Over time, its transmission has shifted from oral tradition to modern media. In today's globalized world, factors such as audience fragmentation, cultural diversity, and digital communication pose challenges to its spread. This underscores the need for innovative approaches to promote Nanyin while preserving its essence. Leveraging technology, collaborating with diverse artists, and engaging communities can support its revival. For instance, the 4th World Nanyin Conference, held from May 31 to June 2, 2024, in Selangor, Malaysia, featured 29 Nanyin groups from China, Singapore, Indonesia, the Philippines, and beyond, highlighting its growing international appeal.

In contemporary society, Nanyin has moved beyond traditional live performances to reach audiences through television, radio, and the internet. The success of these platforms is essential to its influence and acceptance. Therefore, establishing a scientific and systematic framework to evaluate Nanyin's performance across platforms and regions is crucial for its promotion and preservation. Traditional evaluation methods often overlook the complexity of Nanyin's dissemination, focusing only on coverage or audience feedback, while ignoring factors such as content quality, media exposure, and audience engagement. To preserve Nanyin's cultural essence in the modern era, more comprehensive assessment methods are needed. Nanyin, often called a "living fossil" of Chinese music, is valued for its rich heritage and unique performance style. Research spans its history, musical structure, artistic forms, and challenges in modern transmission. Wu explored its historical and cultural value,(1) Chen analyzed its musical features,(2) whereas Li and Lin studied its modern development and preservation strategies.(3) As digital technology and globalization progress, attention to Nanyin's dissemination through diverse media platforms has increased. This makes the scientific evaluation of its effectiveness more important than ever. Scholars have proposed various frameworks: McQuail emphasized channel diversity, content depth, exposure, and engagement,(4) Napoli focused on audience reach and content update frequency,(5) and Rust and Oliver highlighted audience satisfaction and loyalty.(6)

Building on previous research, in this paper, we propose a framework to evaluate the dissemination effectiveness of Nanyin. It includes five main indicators: dissemination channel diversity and coverage, content quality, media exposure, audience engagement, and satisfaction, along with related sub-indicators. The Delphi method, originally developed for structured forecasting, involves rounds of expert feedback to reach a consensus. The analytic hierarchy process (AHP), created by Saaty in the 1970s,(7) breaks down complex decisions into smaller criteria for prioritization. Fuzzy-AHP extends AHP by incorporating fuzzy logic to handle uncertainty in human judgment.(8) By combining the Delphi method and Fuzzy-AHP, the framework integrates expert insights with quantifiable evaluation, covering both qualitative and quantitative aspects. The Delphi method identifies key indicators through expert consensus, whereas Fuzzy-AHP assigns weights to them, enhancing the accuracy and objectivity of the evaluation process.(9,10) In addition, IoT serves as a real-time data-receiving platform, collecting data on audience behavior, media usage patterns, and engagement. These continuous, real-world inputs complement expert opinions and help validate the model, improving the framework's responsiveness and relevance in evaluating Nanyin's communication across platforms.

The rise of IoT has generated a vast amount of data, including both objective quantitative metrics and subjective qualitative information. Despite this, few studies have explored integrating the Delphi method, Fuzzy-AHP, and IoT technology. Using IoT as a data-receiving platform offers significant advantages, such as it enables continuous, real-time data collection from various sources, providing a dynamic input base to support expert analysis and decision-making. The Delphi method relies on iterative expert feedback to forecast trends, which can be considerably enhanced by IoT data streams that reflect real-world conditions in real time. For instance, in smart homes, IoT sensors predict user behavior changes, informing product design and service delivery. Similarly, in cultural domains such as Nanyin dissemination, IoT can gather audience engagement metrics, location-based attendance data, and feedback through connected devices, offering fresh, real-time input to refine expert opinions. Fuzzy-AHP excels in handling vague and uncertain information. When supported by real-time IoT data, it becomes more robust, allowing decision-makers to weigh factors such as cost, performance, and reliability with greater accuracy. IoT also enables continuous environmental and system monitoring, feeding data into both Delphi and Fuzzy-AHP models to refine judgments and improve prediction accuracy. Moreover, IoT functions as a real-time monitoring and alert system, which, when integrated with Fuzzy-AHP, enhances risk prioritization and response. This combined framework supports intelligent systems that adapt on the basis of both historical and current data. Ultimately, using IoT as a core data-receiving platform enables the development of a responsive evaluation system especially applicable to assessing the effectiveness of Nanyin communication across regions and media platforms.

## 2. Methodology

The process of creating an evaluation system for Nanyin promotion and dissemination effectiveness combines IoT, sensor technology, the Delphi method, and Fuzzy-AHP. In this system, IoT-enabled sensors (such as audio environment sensors, infrared people counters, and wearable physiological sensors) are deployed during Nanyin promotion activities to collect real-time data on audience behavior, engagement, and environmental context. These sensors measure variables such as crowd density, motion pattern, sound level, and emotional response (e.g., through heart rate or galvanic skin response), providing quantifiable metrics of audience interaction. The sensor data is then transmitted and processed through an IoT platform, enabling the remote monitoring and data-driven analysis of promotion effectiveness. The Delphi method is employed to gather expert opinions on critical success factors, with iterative refinement to ensure consensus. These factors are then integrated with sensor-derived metrics using Fuzzy-AHP to construct a multi-criteria decision-making framework, accounting for uncertainty and subjective judgments. By incorporating real-time sensor data into the evaluation process, we demonstrate a novel application of sensing technologies within a cultural and promotional context, aligning with the interdisciplinary scope of *Sensors and Materials*. This integration not only enhances the objectivity and reliability of the evaluation system but also highlights the potential of sensor-based approaches in assessing the impact of public engagement activities.

### 2.1 Construction of IoT system and collections of survey and questionnaire data

To ensure a rigorous and data-driven evaluation of Nanyin promotion effectiveness, we incorporated a comprehensive sensor-based IoT framework. At the core of our system lies the deployment of multiple types of sensor, including environmental sensors, audio sensors, GPS modules, and video capture devices. Environmental sensors are used to collect contextual data such as temperature, humidity, ambient noise levels, and lighting conditions, which are known to affect audience perception and comfort during cultural events. These data provide a quantitative foundation for understanding how external factors may affect the reception of Nanyin performances. In parallel, audio sensors are strategically installed to monitor sound playback conditions, including signal clarity, amplitude consistency, and fidelity across different locations. These sensors help assess whether the technical delivery of Nanyin music meets acoustic expectations, thus ensuring that variations in audience feedback can be correlated with measurable sound quality parameters. GPS tracking devices are integrated into mobile or temporary Nanyin installations to capture spatial deployment data, allowing for the precise geolocation analysis of dissemination patterns and regional reach. In addition, video cameras are placed on-site to record real-time audience interaction, which can be processed via computer vision techniques to extract behavioral metrics such as attention span, crowd density, and engagement level.

These sensing components are interconnected through an IoT communication infrastructure designed to accommodate diverse environmental and deployment scenarios. We employed several network topologies such as mesh, star, and tree structures to ensure robustness and scalability in both urban and rural areas. Communication protocols including 5G, Wi-Fi 6, and LoRaWAN were selectively used on the basis of specific transmission requirements: 5G and Wi-Fi 6 offer high-speed, low-latency transmission suitable for video and audio streams, whereas LoRaWAN is ideal for low-power, long-distance environmental sensing. The real-time sensor data are then collected and transmitted to a centralized IoT platform, where data fusion techniques are applied to integrate multisource information into a unified dataset. By embedding sensor technology into the evaluation process, we not only captured objective, high-resolution data on audience experience and dissemination scope, but also demonstrated a meaningful and innovative application of IoT sensing systems within a cultural heritage context. The integration of sensing technologies with intelligent evaluation methods such as Fuzzy-AHP reinforces the relevance of this study to the scope of advancing sensor applications for nontraditional but impactful domains. In this study, we used 5G network technology, which offers several advantages.

(a) High-speed data transmission: The 5G system provides extremely high data transfer rates, supporting fast data flow and applications requiring large bandwidths.

(b) Low latency: The 5G system features very low latency, benefiting real-time applications and instant data processing.

(c) High capacity: The 5G system can connect a large number of devices simultaneously, making it ideal for high-density IoT environments.

(d) High reliability: The 5G system also offers enhanced network reliability, suitable for applications with high stability requirements.

Additionally, the widespread availability of cell phones means that connecting to a 5G network is one of the fastest and most convenient ways to achieve connectivity. In this study, IoT technology was successfully employed to collect and analyze questionnaire data related to Nanyin. A comprehensive system of sensors and data collection equipment was set up, including environmental and audio sensors, which effectively captured data on playback conditions, sound quality, and the usage of audio equipment during Nanyin performances. These sensors also facilitated the collection of audience feedback in real time. To track the geographic distribution of Nanyin events and assess their regional impact, GPS tracking devices were deployed. Additionally, video cameras were installed at multiple locations to document on-site activities and allow for visual comparison across different performance venues. The IoT system operated through various communication topologies, including mesh and star networks, ensuring stable and efficient data flow. Among the available communication technologies, the 5G network was chosen owing to its superior capabilities. Its high-speed data transmission allowed for the swift upload and synchronization of questionnaire responses and sensor data. The low latency of the 5G system supported real-time data processing, while its high capacity enabled the simultaneous operation of numerous IoT devices across different venues. Furthermore, the high reliability of the network ensured consistent and uninterrupted data collection. The use of mobile devices and the widespread availability of 5G connectivity further streamlined the data transmission process, making it fast and convenient for participants to submit questionnaire responses. Through the integration of these technologies, we were able to conduct in-depth analyses of public perception, engagement patterns, and environmental factors affecting the Nanyin experience.

### 2.2 Mathematical model

Fuzzy-AHP combines fuzzy set theory with AHP to handle uncertainty in expert pairwise comparisons. It uses triangular fuzzy numbers, represented as $\tilde{A} = (l, m, u)$, where l is the minimum value, m is the most likely value, and u is the maximum value, as shown in Fig. 1. The membership function $\mu_{\tilde{A}}(x)$ for this triangular fuzzy number is defined as

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & \text{if } x < l \\ \dfrac{x-l}{m-l} & \text{if } l \le x \le m \\ \dfrac{x-l}{m-l} & \text{if } m \le x \le u \\ 0 & \text{if } x > u, \end{cases} \tag{1}$$

where $l \le m \le u$. In a fuzzy judgment matrix, for any two factors $C_i$ and $C_j$, the fuzzy weight of the pairwise comparison matrix is represented by a triangular fuzzy number $\tilde{a}_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right)$, and it satisfies $\tilde{a}_{ij} \cdot \tilde{a}_{ij} = 1$.

The steps of fuzzy-AHP analysis are listed below.

(a) Construct the hierarchical model: Break down the problem into multiple levels (goal, criteria, and alternatives) on the basis of its complexity.

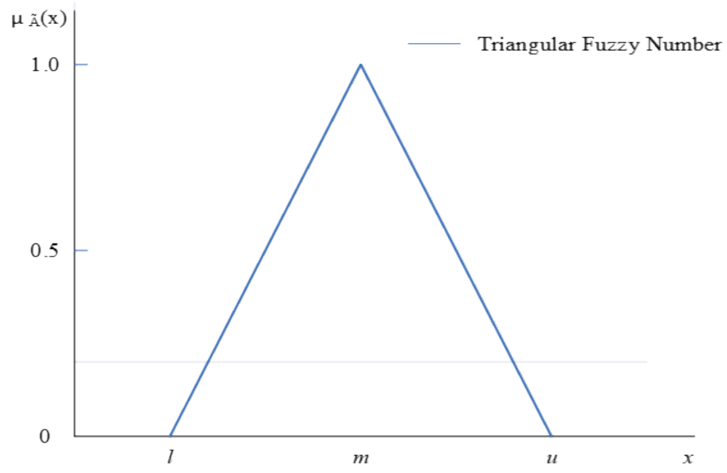


Fig. 1. (Color online) Triangular Fuzzy number membership function.

(b) Develop the fuzzy judgment matrix: Experts make pairwise comparisons at each level, creating a fuzzy judgment matrix with triangular fuzzy numbers to represent the importance ratios.

(c) Calculate the fuzzy synthetic weight vector: Compute the sum of fuzzy numbers in each column.

$$S_j = \sum_{i=1}^{n} \tilde{a}_{ij} \quad \text{for } j = 1, 2, 3 \cdots, n \tag{2}$$

Next, calculate the fuzzy weight vector $\tilde{W}_i$.

$$\tilde{W}_i = \frac{\sum_{j=1}^{n} \tilde{a}_{ij}}{n} \quad \text{for } i = 1, 2, 3, \cdots, n \tag{3}$$

The fuzzy weight vector is represented as $\tilde{W}_i = \left(\tilde{l}_i, \tilde{m}_i, \tilde{u}_i\right)$, where $\tilde{l}_i$, $\tilde{m}_i$, and $\tilde{u}_i$ represent the minimum, most likely, and maximum values of the fuzzy number, respectively.

(d) To obtain clear, usable weights from fuzzy numbers, defuzzification methods are used. Common defuzzification methods include the maximum membership degree and the centroid method. One formula to calculate a defuzzified weight $W_i$ is

$$W_i = \frac{\tilde{l}_i + 4\tilde{m}_i + \tilde{u}_i}{6}. \tag{4}$$

(e) Like in traditional AHP, a consistency check is needed to ensure that expert comparisons are logical and not very inconsistent. In fuzzy AHP, this is performed using the defuzzified matrix.

(f) After defuzzification, the weights need to be normalized so that they add up to 1.

$$W' = \frac{W}{\sum_{i=1}^{n} W_i} \tag{5}$$

(g) Finally, calculate the weights for each option or criterion and rank them to find the best choice or the correct priority order.

## 3. Construction of Evaluation System for Dissemination Effect of Nanyin

### 3.1 Construction of indicator system

Through a review of the literature, researchers initially proposed six main indicators and thirty sub-indicators to assess the dissemination effect of Nanyin. To enhance the objectivity and comprehensiveness of the evaluation process, IoT-based data collection techniques were incorporated throughout the framework development. Specifically, sensor modules such as RFID readers, infrared counters, environmental sensors, and video analytics systems were deployed at Nanyin performance venues and exhibition spaces to gather real-time audience behavior data, including foot traffic, dwell time, ambient sound levels, and audience movement patterns. Additionally, online engagement data were collected through web analytics and social media monitoring tools linked to IoT infrastructure, providing quantitative insights into digital media exposure and user interactions. After the first round of expert consultations using the Delphi method, five sub-indicators were removed or merged owing to low average scores and high standard deviations, indicating lower importance. In the second round, the main indicators were refined to five and the sub-indicators were reduced to fifteen. To enhance the diversity and expertise of the panel, four new experts were added. The third round of expert consultations showed higher average scores and lower standard deviations for most indicators, while a few with moderate scores and higher variations were further adjusted on the basis of expert input. In the end, the evaluation framework was finalized, consisting of five main indicators: the diversity and reach of communication channels, content quality, media exposure, audience engagement, and audience satisfaction. Each of these is supported by several sub-indicators, as detailed in Table 1, with the overall structure shown in Fig. 2.

### 3.2 Determination of weights and fuzzy judgment

We used Fuzzy-AHP to determine the importance of different indicators in evaluating the dissemination of southern music. To ensure that the system is both scientific and practical, the process followed these steps.

(a) Over 40 responses were collected, and after removing incomplete or inconsistent ones, 30 valid samples were selected. The experts, chosen for their relevant knowledge and experience, provided paired comparison data on both primary and secondary indicators using triangular

Table 1
Primary and secondary indicators of Nanyin dissemination effect evaluation system and related literature.

| Primary indicator | Secondary indicator | Related literature |
|---|---|---|
| Diversity and coverage of transmission channels | Diversity of transmission platforms | References 4 and 11 |
| | Coverage breadth of transmission channels | References 5 and 12 |
| | Audience distribution and coverage depth | References 13 and 14 |
| Quality of dissemination content | Content depth | References 15 and 16 |
| | Content diversity | References 17 and 18 |
| | Content accuracy | References 19 and 20 |
| | Content update frequency | References 21 and 22 |
| Media exposure | Number of media reports | References 23 and 24 |
| | Reports by key media | References 25 and 26 |
| | Media coverage | References 27 and 28 |
| Audience engagement | Audience interaction and engagement | References 29 and 30 |
| | Quantity of activity feedback | References 31 and 32 |
| Audience satisfaction | Audience feedback and adoption | References 33 and 34 |
| | Audience satisfaction surveys | References 4 and 35 |
| | Audience loyalty | References 36 and 37 |

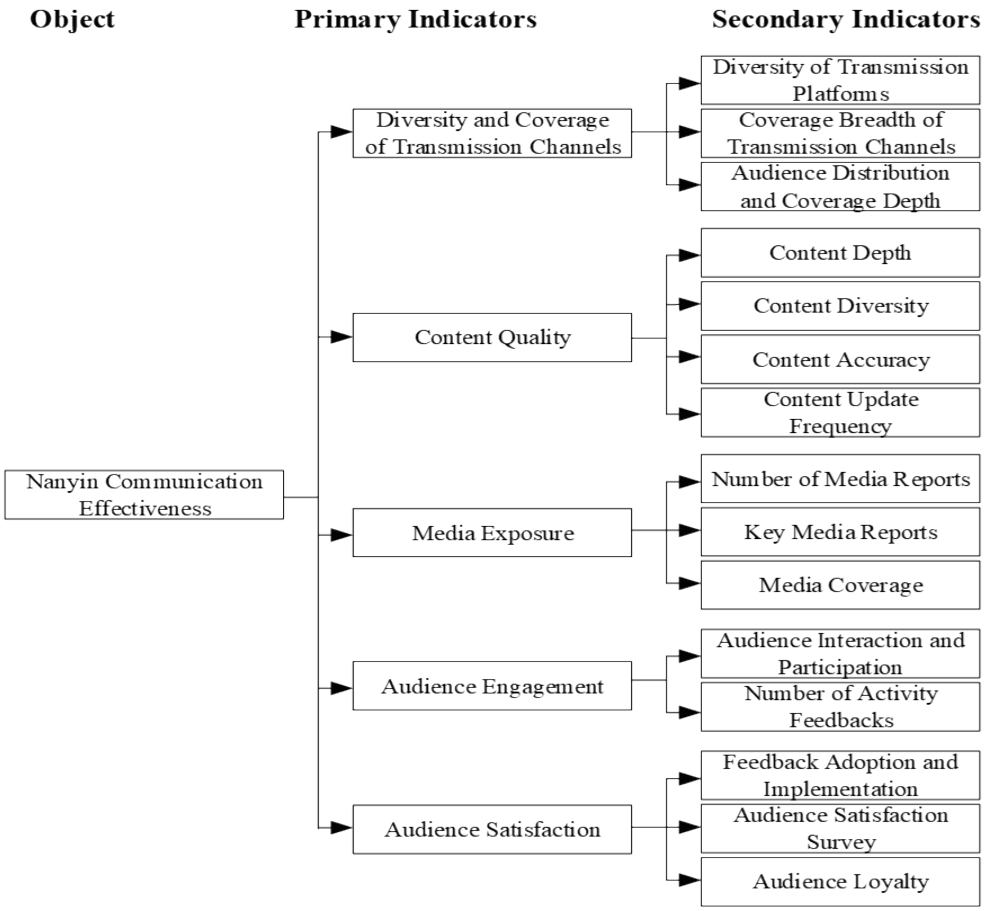


Fig. 2. Hierarchical structure diagram for evaluating the dissemination effects of Nanyin.

fuzzy numbers $\tilde{A} = (l, m, u)$ to express their judgments, representing the lowest, most likely, and highest values. This method helps handle uncertainty in expert opinions and improves accuracy.

(b) We summed and normalized the fuzzy judgment matrix to obtain the fuzzy weight vector $\tilde{W}_i$ [Eq. (3)], turning expert input into measurable values for analysis.

(c) We applied the centroid method to defuzzify the weights, converting the fuzzy value $W_i$ [Eq. (4)] into a clear numerical one that shows the relative importance of each indicator. This step makes the results easier to interpret and apply.

Finally, by combining the expert questionnaire results, we completed the weight structure for the southern music evaluation system. The fuzzy, defuzzified, and normalized weights are shown in Tables 2 and 3.

In the evaluation system for how effectively Nanyin is being spread, Fuzzy-AHP was used to determine the levels of importance (weights) of different factors. Here is a summary of the main indicators and what their weights mean.

Table 2
Weights of primary indicators.

| Primary indicator | Fuzzy comprehensive weight vector $\tilde{W}_i$ | Defuzzified weight $W_i$ | Normalized weight $W'$ |
|---|---|---|---|
| Diversity and coverage of transmission channels | (0.327, 0433, 0.540) | 0.433 | 0.230 |
| Quality of content dissemination | (0.347, 0.454, 0.561) | 0.454 | 0.241 |
| Media exposure | (0.253, 0.359, 0.466) | 0.359 | 0.190 |
| Audience engagement | (0.215, 0.321, 0.428) | 0.321 | 0.170 |
| Audience satisfaction | (0.213, 0.319, 0.426) | 0.319 | 0.169 |

Table 3
Weights of secondary indicators.

| Secondary indicator | Fuzzy comprehensive weight vector $\tilde{W}_i$ | Defuzzified weight $W_i$ | Normalized weight $W'$ |
|---|---|---|---|
| Diversity of transmission platforms | (0.333, 0.437, 0.543) | 0.437 | 0.351 |
| Coverage breadth of transmission channels | (0.333, 0.437, 0.543) | 0.437 | 0.351 |
| Audience distribution and coverage depth | (0.263, 0.370, 0.477) | 0.370 | 0.298 |
| Content depth | (0.371, 0.477, 0.584) | 0.477 | 0.276 |
| Content diversity | (0.300, 0.407, 0.513) | 0.407 | 0.235 |
| Content accuracy | (0.356, 0.463, 0.569) | 0.463 | 0.267 |
| Content update frequency | (0.278, 0.385, 0.491) | 0.385 | 0.222 |
| Number of media reports | (0.339, 0.445, 0.552) | 0.445 | 0.335 |
| Reports by key media | (0.367, 0.473, 0.580) | 0.473 | 0.356 |
| Media coverage | (0.303, 0.410, 0.517) | 0.410 | 0.309 |
| Audience interaction and engagement | (0.374, 0.481, 0.587) | 0.481 | 0.528 |
| Quantity of activity feedback | (0.323, 0.430, 0.537) | 0.430 | 0.472 |
| Audience feedback and adoption | (0.330, 0.437, 0.543) | 0.437 | 0.330 |
| Audience satisfaction surveys | (0.389, 0.496, 0.603) | 0.496 | 0.374 |
| Audience loyalty | (0.285, 0.391, 0.498) | 0.391 | 0.296 |

### 3.3 Primary indicators

(a) Diversity and coverage of transmission channels (weight: 23%): This shows that using various platforms (such as TV, internet, and radio) is important for reaching a wider audience and improving how well Nanyin is spread.
(b) Quality of content dissemination (weight: 24.1%): This is the most important factor because it highlights that the depth, accuracy, and variety of the content are keys to effectively sharing the cultural essence of Nanyin and keeping the audience interested.
(c) Media exposure (weight: 19%): How often and widely Nanyin is covered in the media help raise public awareness and influence.
(d) Audience engagement (weight: 17%): Getting the audience involved and encouraging participation are important for increasing their interest and support for Nanyin.
(e) Audience satisfaction (weight: 16.9%): Although it has the lowest weight, audience satisfaction still matters. Positive feedback helps build long-term loyalty and good reputation.

### 3.4 Secondary indicators

(a) Diversity and coverage of transmission channels: Both the variety of platforms and the breadth of channel coverage are equally important, each contributing 35.1%. This means that expanding platforms and channels can help spread Nanyin more widely and increase its impact.
(b) Quality of content dissemination: Content depth and accuracy are most important here, with weights of 27.6 and 26.7%, respectively. High-quality content is key to keeping audiences engaged and conveying Nanyin's cultural essence.
(c) Media exposure: Coverage by key media is the most important factor, with a weight of 35.6%. Broad media exposure can considerably increase public attention to Nanyin.
(d) Audience engagement: Interaction and participation are the most important, making up 52.8%. Improving engagement can boost awareness and enthusiasm for Nanyin.
(e) Audience satisfaction: Surveys measuring satisfaction have the largest weight at 37.4%. This feedback is crucial for improving dissemination strategies.

Fuzzy-AHP highlights the relative importance of each factor in evaluating Nanyin's dissemination. The weights reflect expert consensus and provide a solid foundation for developing effective strategies to maximize Nanyin's cultural impact in a diverse media environment. To support this framework, sensor technologies play a critical role in enhancing the accuracy and depth of data collection within the IoT-enabled dissemination infrastructure. Environmental sensors (e.g., temperature, humidity, and sound level) and biometric sensors (e.g., heart rate, facial expression detection, and galvanic skin response) can be deployed in both physical and digital interaction environments to monitor audience behavior and emotional responses during Nanyin performances. These sensors enable the automated capture of real-time data on audience engagement, such as the duration of attention, the movement within exhibition spaces, the frequency of interactions with specific media elements, and even physiological reactions that indicate levels of interest or resonance. Additionally, networked IoT devices facilitate the continuous transmission and aggregation of the data to cloud-based or edge-computing platforms, where they can be processed to generate actionable insights. By integrating the sensor-derived behavioral data into the evaluation model, cultural practitioners and researchers can more accurately assess how different dissemination strategies affect audience reception. This closed-loop data feedback mechanism not only strengthens the empirical basis of the Fuzzy-AHP analysis but also supports the dynamic refinement of content delivery methods, ultimately fostering a more personalized, interactive, and impactful cultural experience of Nanyin.

## 3.5 Consistency check and final weight determination

To ensure the reliability of expert input, we calculated the consistency ratio (CR) for each fuzzy judgment matrix. A CR below 0.1 means that the judgments are consistent. In this study, all experts met this standard, showing that their evaluations were reliable. We then used the fuzzy weight vectors from 30 experts to calculate the final weights for both first and second indicators, as shown in Table 4. These weights show the relative importance of each factor in evaluating how effectively Nanyin is being disseminated and offer a solid basis for creating practical dissemination strategies.

Table 4
Comprehensive weights of primary and secondary indicators in the Nanyin dissemination effectiveness evaluation system. $W'^*$: comprehensive weight

| Primary indicator | $W'$ | Secondary indicator | $W'$ | $W'^*$ |
|---|---|---|---|---|
| Diversity and coverage of transmission channels | 0.230 | Diversity of transmission platforms | 0.351 | 0.081 |
| | | Coverage breadth of transmission channels | 0.351 | 0.081 |
| | | Audience distribution and coverage depth | 0.298 | 0.069 |
| Quality of dissemination content | 0.241 | Content depth | 0.276 | 0.067 |
| | | Content diversity | 0.235 | 0.057 |
| | | Content accuracy | 0.267 | 0.064 |
| | | Content update frequency | 0.222 | 0.054 |
| Media exposure | 0.190 | Number of media reports | 0.335 | 0.064 |
| | | Reports by key media | 0.356 | 0.068 |
| | | Media coverage | 0.309 | 0.059 |
| Audience engagement | 0.170 | Audience interaction and engagement | 0.528 | 0.090 |
| | | Quantity of activity feedback | 0.472 | 0.080 |
| Audience satisfaction | 0.169 | Audience feedback and adoption | 0.330 | 0.056 |
| | | Audience satisfaction surveys | 0.374 | 0.063 |
| | | Audience loyalty | 0.296 | 0.050 |

### 3.6 Significance of primary and secondary indicators

By calculating the weighted average of fuzzy weight vectors from 30 experts, we determined the final weights for the primary and secondary indicators in evaluating Nanyin dissemination. To enhance the reliability and objectivity of the evaluation process, the data collected through IoT-enabled systems, such as audience tracking sensors, smart environmental monitoring devices, and online interaction logs, were integrated with expert judgments. These IoT-driven data sources provided empirical support for refining indicator weights by offering real-time feedback on audience behavior, spatial usage, and digital engagement level. These weights guide the development of effective dissemination strategies, helping communicators allocate resources efficiently and optimize outcomes. Below are the primary indicators and their significance.

(a) Diversity and coverage of transmission channels (0.230): These indicators stress the importance of using various channels to reach a wide audience. A broad range of platforms ensures that Nanyin reaches more people, enhancing its social impact.

(b) Quality of disseminated content (0.241): This is the most important primary indicator, highlighting that high-quality, accurate, and diverse content is essential for effective communication. Well-crafted content helps convey Nanyin's cultural essence and fosters long-term audience engagement.

(c) Media exposure (0.190): Media exposure is key to boosting Nanyin's visibility. Coverage in mainstream media increases public awareness and influence, enhancing the overall impact.

(d) Audience engagement (0.170): Engagement reflects the importance of audience interaction and feedback. Improving audience participation boosts interest and loyalty, promoting deeper cultural transmission.

(e) Audience satisfaction (0.169): While it has a lower weight, audience satisfaction is still crucial for assessing the effectiveness of dissemination. It shows how well the audience accepts and continues to engage with Nanyin.

The secondary indicators and their significance are listed below.

(a) Diversity and coverage of transmission platforms (0.081, 0.081): These indicators stress the importance of using diverse communication platforms and expanding their reach to enhance Nanyin's dissemination.

(b) Audience interaction and engagement (0.090): This is the most important secondary indicator, because it emphasizes that increasing audience interaction improves Nanyin dissemination effectiveness.

(c) Content depth (0.067) and content accuracy (0.064): These indicators focus on how the depth and accuracy of content affect its impact. High-quality content is essential for attracting and maintaining an audience.

(d) Coverage by key media (0.068): This shows the importance of media exposure from key outlets, as coverage by authoritative media boosts Nanyin's social recognition and dissemination effectiveness.

(e) Audience satisfaction surveys (0.063): These surveys provide valuable feedback on audience satisfaction, helping improve dissemination strategies and overall effectiveness.

The determination of these weights helps guide resource allocation and strategy formulation.

By focusing on high-weight indicators such as improving content quality, diversifying channels, and boosting audience interaction, communicators can more effectively promote Nanyin, ensuring that its cultural value is widely recognized and communicated.

## 4. Empirical Analyses

At the 2017 BRICS Summit in Xiamen, Nanyin performances were a key part of the evening event, as shown in Fig. 3, highlighting the importance of Nanyin as an intangible cultural heritage. To test the effectiveness of the evaluation system, we used the performance "Hundred Birds Returning to the Nest", as shown in Fig. 4, from the 2023 Spring Festival Gala as a case study. This program was selected for its rich cultural heritage and emotional depth. We conducted an online survey with 84 responses, 82 of which were valid. The respondents came from various genders, professions, and educational backgrounds. Of the respondents, 21.95% were male, 78.05% were female, 71.95% had expertise in Nanyin, and 53.66% were students. The survey used a five-point scale (strongly agree = 5, agree = 4, neutral = 3, disagree = 2, and strongly disagree = 1), and raw scores were weighted on the basis of expert opinions. The final results, including raw and weighted scores, are shown in Table 5.

In the evaluation of the "Hundred Birds Returning to the Nest" case, the performance across various dimensions of dissemination effectiveness is as follows.


Fig. 3. (Color online) Nanyin performances at the BRICS Summit held in Xiamen in 2017.

Fig. 4. (Color online) "Hundred Birds Returning to the Nest" from the 2023 Lunar New Year Gala.

Table 5
Raw and weighted scores for "Hundred Birds Returning to the Nest".

| Primary indicator | Secondary indicator | Raw score | Weighted score |
|---|---|---|---|
| Diversity and coverage of transmission channels | Diversity of transmission platforms | 4.585 | 0.371 |
| | Coverage breadth of transmission channels | 4.561 | 0.369 |
| | Audience distribution and coverage depth | 4.524 | 0.312 |
| Quality of dissemination content | Content depth | 4.537 | 0.304 |
| | Content diversity | 4.610 | 0.263 |
| | Content accuracy | 4.622 | 0.296 |
| | Content update frequency | 4.549 | 0.246 |
| Media exposure | Number of media reports | 4.415 | 0.283 |
| | Reports by key media | 4.451 | 0.303 |
| | Media coverage | 4.451 | 0.263 |
| Audience engagement | Audience interaction and engagement | 4.573 | 0.412 |
| | Quantity of activity feedback | 4.549 | 0.364 |
| Audience satisfaction | Audience feedback and adoption | 4.561 | 0.255 |
| | Audience satisfaction surveys | 4.556 | 0.287 |
| | Audience loyalty | 4.500 | 0.225 |

### 4.1 Diversity and coverage of transmission channels

The diversity of transmission platforms and the coverage of transmission channels received high scores, indicating that "Hundred Birds Returning to the Nest" effectively reached its audience through various platforms and extensive coverage. The integration of IoT technologies, such as real-time audience monitoring, location-based analytics, and platform-specific interaction tracking, further validated the breadth of this outreach by providing empirical data on audience distribution across different regions and digital platforms. Although audience distribution and coverage depth scored slightly lower, the IoT-based data still demonstrated good dissemination effectiveness and revealed patterns that may not be captured through traditional surveys alone. These insights suggest that there is potential to further enhance dissemination depth in certain regions by leveraging localized IoT feedback and adaptive content delivery strategies.

### 4.2 Quality of disseminated content

Content depth and content accuracy received high scores, highlighting the importance of professional and credible content in achieving effective dissemination. Content diversity and content update frequency had relatively lower weights, but they still contribute to maintaining audience interest.

### 4.3 Media exposure

Coverage by key media received a high weight, indicating the crucial role that authoritative media plays in enhancing the program's impact. Although media coverage showed some shortcomings, the overall level of exposure was still high.

### 4.4 Audience engagement

Audience interaction and engagement received a high score, demonstrating that increasing interactivity is a key strategy for improving dissemination effectiveness. Activity feedback quantity also performed well, indicating active audience participation and effective feedback.

### 4.5 Audience satisfaction

Audience satisfaction surveys and audience loyalty received high scores, showing that the program has achieved widespread recognition and sustained attention. However, their overall weight in the dissemination assessment was relatively lower.

### 4.6 Overall analysis

The overall assessment indicates that "Hundred Birds Returning to the Nest" excelled in key indicators such as the diversity and coverage of transmission channels, content quality, and audience engagement. Future optimization should focus on improving audience distribution and coverage depth, as well as increasing the frequency of content updates to further enhance dissemination effectiveness.

## 5. Conclusions

We developed a scientifically rigorous evaluation system for the promotion and dissemination effectiveness of Nanyin by integrating IoT, the Delphi method, and Fuzzy-AHP. Under the use of IoT, the programs centered around Nanyin were rapidly promoted and disseminated, and detailed feedback was provided by different individuals regarding various promotion and dissemination systems. The system encompasses multiple key evaluation dimensions and enhances the objectivity and accuracy of the assessment through quantified weighting. The results indicate that this evaluation system effectively captures the multilayered performance of Nanyin throughout the dissemination process, providing systematic support for the preservation and promotion of Nanyin culture. Future research can focus on the following areas for optimization and expansion:

(a) Dynamic optimization of the evaluation model: As the dissemination environment and audience preference change, a dynamic evaluation mechanism can help by adjusting indicator weights in real time, improving the model's flexibility and accuracy.

(b) Expansion of application scope: The evaluation system can be applied to study the effects of other intangible cultural heritage items, validating its use in different cultural contexts and supporting preservation strategies.

(c) Data-driven optimization strategies: Future research can use big data and AI to gain deeper insights, offering more precise guidance for improving the model and developing dissemination strategies.

In summary, the Nanyin dissemination evaluation system developed in this study is significant for advancing the modern dissemination of Nanyin and ensuring the long-term preservation of its cultural value. Additionally, it offers a valuable reference for academic research and practical applications in the field of cultural dissemination.

## Acknowledgments

The works are supported by 2024 Major Project of the Fujian Provincial Social Science Research Base: "Digital Education Research on Nanyin from the Perspective of New Productive Forces" (Project No. FJ2024JDZ073) and 2023 The projects of Social Science and Art general project “Research on the Discourse System of Nanyin Theory” (Project No. 23BD069).

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