Collaborative Recommendation of National Image Resources for Targeted International Communication via Multidimensional Features and E-CARGO Modeling

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***Abstract*—With the acceleration of globalization, the targeted international communication of national images contributes to enhancing a nation's soft power and international recognition. It is challenging to select appropriate resources from the mass candidates for creating promotional works of national image. Existing research only focuses on the methodologies and lacks the systematic modeling and solving of national image resources recommendation. A collaborative recommendation approach to national image resources is proposed for targeted international communication. In it, the multidimensional features of national image resources and characteristics of communication audiences are modeled, and an evaluation mechanism is proposed to measure the comprehensive compatibility between national image resources and communication audiences. By innovatively introducing the role-based collaboration (RBC) theory and the environment-classes, agents, roles, groups, and objects (E-CARGO) model, the national image resources recommendation is formalized as a collaborative optimization problem. The mathematical model is built and solved via an optimization package. Finally, the case study and experiments show that the approach is efficient, feasible, and conducive to enhancing the efficiency of selecting national image resources. It offers a novel research paradigm for targeted international communication.**

***Index Terms*—Collaborative recommendation, environment-classes, agents, roles, groups, and objects (E-CARGO), national image resource, targeted international communication.**

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I. Introduction

A. Motivations

GLOBALIZATION has become a major trend in the contemporary world, accelerating the development of international relations and fostering closer connections among nations. In this context, the targeted international communication of national images is fast becoming a key instrument in international political and economic competition. A successful international communication is of great significance for building a national image, enhancing the international speech right, and developing national soft power [1]. To achieve the targeted international communication, it is necessary to segment the communication audiences by clarifying their characteristics. Moreover, the personalized services are provided to different communication audiences to improve the international communication effect [2].

In recent years, researchers have generated numerous high-quality theoretical contributions in the field of building national image strategies and international communication strategies [3]. In terms of building national image strategies, existing research [4] emphasizes that the concept of a national image should be defined clearly, and the multiple dimensions of building a national image should be analyzed deeply. Furthermore, a national image would be built via mining and organizing abundant and multimode national image resources. Regarding the international communication strategies of national image, existing research [5] indicates that the international communication of national images is cross-cultural, because many countries and regions are different in societal systems, ideologies, and religious beliefs. Therefore, to better present the national image and guide public attention, it is necessary to study the communication mechanisms of public opinion, identify the characteristics of different communication audiences. From existing studies, it can be found that the international communication of national images is still concentrated on theoretical exploration. So far, there is no feasible approach to building national images and facilitating international communication from the perspective of mathematical modeling and algorithm implementation.

National image resources are representative materials related to a country's certain aspects, such as economy, politics, culture, and society. For example, in China, landmarks like the Temple of Heaven, the Forbidden City, and the Great Wall symbolize China's profound cultural heritage. In addition, cultural symbols, such as the erhu, tai chi, and qipao, represent the diverse artistic forms of China. These elements are typical examples of China's national image. They frequently appeared in promotional videos during the 2008 Beijing Olympics and the closing ceremony of the Athens Olympics, reflecting the characteristics of China's joyful and festive, rich heritage, and innovative national image.

These resources are presented in various modalities, e.g., videos, audio, text, etc. They serve as the foundational and supportive elements for creating promotional works for national image. For instance, a video "In Russia" consists of multiple types of resources, including a poem named "Ancestral Land" from a former Soviet poet, a breathtaking natural scenery video from the Bering Strait to Vladivostok, a video of the Soviet Red Army soldiers performing the "Soldier's Dance," and images of Russian military formations. Through meticulous arranging of these national image resources, the video shows the humanities, history, and natural scenery of Russia. However, a country with a long history usually possesses abundant national image resources. For example, over the period of more than 1200 years from the early Middle Ages to the first half of the 20th century, German poets produced countless poems. Similarly, China, with an uninterrupted cultural inheritance of a history of over 5000 years, possesses a huge number of cultural resources. During the Song Dynasty, there were approximately over 270 000 poems. Hence, to construct a good promotional work, the first step is to study how to select suitable resources according to the publicity theme, characteristics of communication audiences, and expected communication effect.

This article proposes a collaborative approach to national image resources recommendation for targeted international communication, denoted as NRR4TIC. This approach selects suitable national image resources for developing promotional works of national image according to the publicity themes and communication strategies. It can enhance the efficiency of constructing a national image and improve the precision of international communication of national images.

B. Contributions

The main contributions of this article are shown as follows.

1) To achieve targeted international communication from the perspective of algorithm design and systematic modeling, a novel approach is proposed by utilizing the role-based collaboration (RBC) theory and the environment-classes, agents, roles, groups, and objects (E-CARGO) model [6], [7], [8], [9]. This approach calculates the comprehensive compatibility between national image resources and communication audiences from multiple dimensions. Based on this, suitable resources are selected via a globally collaborative optimization method. This article provides a new research paradigm of national image resources recommendation for targeted international communication, which can improve the efficiency of international communication and enhance a country's capability of international communication.
2) To ensure the optimal effectiveness of international communication of national images, this article adopts a multidimensional analysis method to model the national image resources and communication audiences. To reduce potential conflicts from cultural differences between resources and communication audiences, we define three types of constraints for effectively preventing the negative propagation effect.

II. Related Work

A. Building National Image

As an important part of a country's soft power, a positive national image is conducive to promoting international exchanges and cooperation, giving full play to its international influence and realizing national interests. Now, scholars have carried out a series of explorations on the strategies for building national image. The existing approaches are mainly divided into two types. The first type focuses on building an unconscious, intrinsic and abstract national image, which encompasses the societal psychology, national character, and value systems implicit in the communication mediums. The second type focuses on building a conscious, external, and concrete national image, i.e., the audio-visual symbols and cultural elements showcased in communication mediums.

1) Building the Intrinsic National Image: By analyzing the YouTube vlogs of internationally renowned high-influence figure Ziqi Li, Whyke et al. [10] revealed how she used emotional associations to construct a complex Chinese image and present a personal image of a "weak and independent" Chinese rural woman. Chen [11] examined whether a nation's performance in the Olympics would influence its national image in the eyes of the Chinese audience.

2) Building the External National Image: Zhong et al. [12] analyzed the data from reports in "Financial Times" and "The Wall Street Journal" spanning from 2011 to 2019 regarding Chinese construction enterprises in Africa. They unveiled the corporate images of these enterprises and put forth recommendations for enhancing their corporate image. Xu and Löffelholz [13] analyzed 2455 news posts published by mainstream newspapers on Twitter (U.S.) and Weibo (China) between 2007 and 2019, revealing how Germany constructs its national image through textual content, visual references, and text–image relationships in multimodal journalism.

In conclusion, a comprehensive national image can be built by leveraging a diverse array of multimodal national image resources, and integrating elements, such as national narratives, cultural heritage, and national ethos.

B. International Communication of National Images

By building a positive national image and employing appropriate international communication strategies for promotion, a nation can enhance its international reputation and standing, attract tourists and investors, facilitate international cooperation and exchange, propel its development and prosperity, and foster cultural exchange. Hence, it is evident that international communication plays an important role in shaping and upholding a national image. The international communication of national images is facilitated by the process of globalization objectively.

Ban and Pan [14] examined how Chinese private enterprises can play the role of national image communicators in the context of the Belt and Road Initiative, and finally identified some key national communication strategies. These strategies are: 1) products and services as the main medium of national image communication; 2) strategic detachment from the state discourse; 3) developmental discourse at the center of understanding the relationship between the Chinese corporation and the local community; and 4) the strategic role of the individual in cross-cultural communication. Panagiotopoulou [15] compared the communication preferences and promotional strategies during the 2004 Athens Olympics and the 2008 Beijing Olympics. Albro [16] used the post-911 U.S. Middle East Shared Values Initiative and the operation of the Confucius Institute in the United States as an example to compare the national soft power strategies of the United States and China, and proposed that the inconsistency between visual image and oral expression hinders the promotion of national soft power and cultural exchanges. Hartig [17] provided an overview of research concerning Chinese international image management, and suggested the need for interdisciplinary studies in this field.

Scholars have contributed some theories and experiences in the fields of national image building and international communication, and some new technologies, such as data mining and deep learning, have been applied to the fields. However, existing research focuses on theoretical analysis, lacking a well-established methodological framework and application system. Moreover, as typical interdisciplinary research involving computer science, existing research only utilizes big data techniques for mining, clustering, or quantitative analyzing the corpus data for supporting the proposed theories. Only Zhao et al. [18] applied information technology to study the national image. They used Faster-RCNN to the object detection of diplomatic videos and performed mathematical statistics on the detection results. They also analyzed how the United States successfully builds a powerful, harmonious, and happy national image. To our best knowledge, currently there is no research on national image resources recommendation for targeted international communication.

C. RBC Theory and E-CARGO Model

The RBC theory [6], [8], [9] emphasizes that members occupying different roles within organizations collaborate and coordinate with each other to achieve global optimal objectives. To enhance an organization's work efficiency, the tasks and responsibilities of each role are clarified, and redundant or conflicting work is prevented. Furthermore, the theory can aid organizations in planning and allocation of resources, and promoting the rational use of resources. The E-CARGO model is an implementation of the RBC theory, providing a computational methodology for analyzing, designing, and simulating complex systems. This model has been applied in many domains, such as services computing [19], smart education [20], human–machine cooperation [21], intelligent transportation [22], and logistics management [23].

In the context of the problem discussed in this article, first, we should quantitatively evaluate the compatibility of different national image resources for various communication audiences. Second, based on specific rules, we need to allocate candidate resources to different communication audiences to achieve optimal global effectiveness. It is evident that this problem embodies the inherent characteristics of an RBC problem. Employing a collaborative optimization approach to the national image resources recommendation can effectively meet the following research requirements.

1) Avoiding the problem of multiple communication audiences experiencing uniform national image communication content. By introducing the E-CARGO model, it is possible to restrict the usage frequency of a resource. A better international communication effect could be achieved through ensuring the diversity of national image resources.
2) Achieving global optimization of communication effect by considering the characteristics of all communication audiences. Traditional methods only focus on formulating objective functions and conducting optimization for a single communication audience. However, the core requirement for targeted international communication of a national image is to achieve global optimization of communication effect across all communication audiences. Therefore, we need to capitalize on the advantages of national image resources fully to conduct the comprehensive optimization under the premise of ensuring diversity in national image communication.
3) Avoiding the deviation of communication effect caused by possible conflicting factors in the propagation process. Traditional methods ignore the potential conflicts between optimization objectives, while the collaborative optimization approach takes into account the differences between objectives and interests of multiple stakeholders. It can make tradeoffs to balance multiple objectives effectively. In this article, the content of national image resources may conflict with specific communication audiences, and the collaborative optimization approach can seek the optimal solution.

III. Basic Models and Related Constraints

In this section, the national image resources and communication audiences are modeled, and then three types of constraints are established.

A. Evaluation Model of National Image Resources

To distinguish the differences of national image resources exactly, a hierarchical model, defined in Fig. 1, is used to evaluate the national image resources according to nine

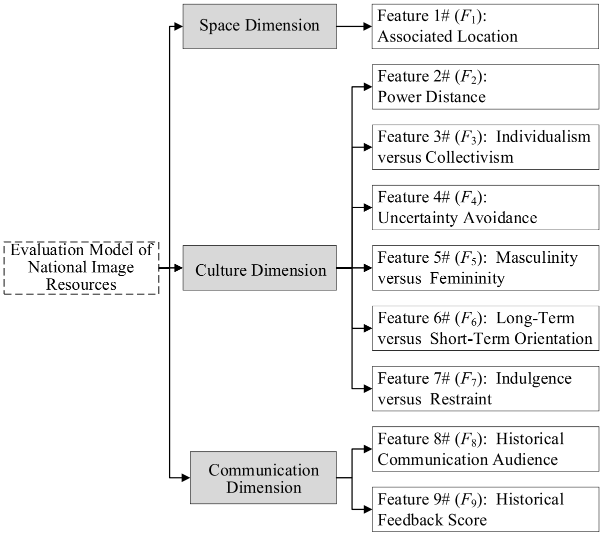

Fig. 1. Evaluation model of national image resources.

features from three dimensions. These dimensions include the following.

1) Space Dimension: It reflects the geographical information associated with the content of national image resources. Existing research indicates that communication audiences prefer to the locally relevant content rather than exotic content of communication [24]. Thus, the spatial location obviously influences the audiences' acceptance level of national image resources. The space dimension comprises one feature, i.e., F_1.

2) Culture Dimension: It reflects the differences in cultural features among different nationalities and regions. Identifying these features is significant for targeted international communication. In this article, Hofstede's cultural dimensions theory [25] is employed to measure cultural differences. This dimension consists of six features, i.e., F_2–F_7.

3) Communication Dimension: It reflects the historical usage of national image resources. The communication effect of resources could be evaluated according to the previous records. This dimension comprises two features, i.e., F_8 and F_9.

The nine features are introduced in detail as follows.

1) *Feature 1# (F_1)—Associated Location:* The geographical coordinates of the content associated with a national image resource are used to describe this feature. For example, the storyline of the movie "The Chorus" takes place in the Burgundy region of France, thus, the F_1's feature value of this movie is (47° 3' 9.017" N, 4° 23' 1.397" E).
2) *Feature 2# (F_2)—Power Distance:* It reflects the extent to which members of a society accept the unequal distribution of power and resources. In high power distance cultures, there is a greater acceptance of hierarchical power structures, whereas low power distance cultures emphasize more equal power distribution.
3) *Feature 3# (F_3)—Individualism Versus Collectivism:* It reflects the degree to which individuals in a society are integrated into groups. Individualistic cultures emphasize personal autonomy, self-expression, and individual achievements, while collectivistic cultures prioritize group harmony, cooperation, and shared goals.
4) *Feature 4# (F_4)—Uncertainty Avoidance:* It reflects a society's tolerance for ambiguity and uncertainty. High uncertainty avoidance cultures prefer structured environments with clear rules, while low uncertainty avoidance cultures are more comfortable with ambiguity and change.
5) *Feature 5# (F_5)—Masculinity Versus Femininity:* It reflects whether a society values qualities typically associated with males, such as competitiveness and decisiveness, or typically associated with females, such as humility and caregiving. A higher value of this feature indicates a society's stronger inclination toward masculinity, emphasizing male qualities, while a lower value suggests a society with a stronger emphasis on female qualities.
6) *Feature 6# (F_6)—Long-Term Versus Short-Term Orientation:* It reflects a society's focus on long-term planning and values. Long-term-oriented cultures emphasize persistence, thrift, and future-oriented thinking, whereas short-term-oriented cultures prioritize immediate rewards and present-focused actions.
7) *Feature 7# (F_7)—Indulgence Versus Restraint:* It reflects the extent to which a society allows for gratification of human desires and impulses. Indulgent cultures prioritize individual happiness and pleasure, while restrained cultures emphasize self-discipline and societal norms.
8) *Feature 8# (F_8)—Historical Communication Audience:* It represents the set of communication audiences that have already experienced this resource. To ensure diversity in results, it is important to avoid repeatedly recommending the same resources to the same audience.
9) *Feature 9# (F_9)—Historical Feedback Score:* It represents the evaluation results provided by communication audiences who have previously experienced one national image resource. The historical feedback on resources is helpful to analyze the degree of liking or disliking of these resources among different communication audiences. This, in turn, provides valuable insights for future recommendation decisions.

The evaluation methods for the above features are introduced in Section V-B. The obtained evaluation values are used to select the candidate national image resources.

B. Evaluation Model of Communication Audiences

An audience refers to the recipient of the information being disseminated. It can be an individual, a group, or a social organization [26]. An accurate analysis of the characteristics of the communication audience is the fundamental prerequisite for targeted international communication. The evaluation model of the communication audience is shown in Fig. 2.

From Fig. 2, each communication audience is evaluated based on nine characteristics from three dimensions (i.e., space, culture, and internationality). Six characteristics

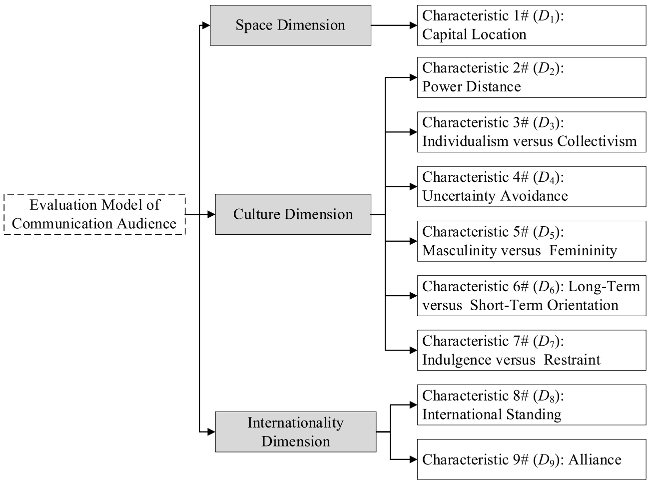

Fig. 2. Evaluation model of communication audiences.

(i.e., $D_2 - D_7$) from the culture dimension share the same connotations as those (i.e., $F_2 - F_7$) in the evaluation model of national image resources. In addition to these six characteristics, the communication audience model possesses three distinct characteristics, which are introduced as follows.

1) Characteristic 1# (D_1)—Capital Location: It represents the geographical location of the capital city of the communication audience. After obtaining the geographical location of the nation capital, we can calculate the distance between the associated location of national image resources and the communication audience. This distance indeed influences people's acceptance level of information.

2) Characteristic 8# (D_8)—International Standing: It represents the international influence of a communication audience (i.e., certain country).

3) Characteristic 9# (D_9)—Alliance: It represents the level of intimacy in the relationship between the communication audience and a specific country. The transmission of a national image between countries with close relationships is more likely to achieve favorable communication effect, thereby enhancing the home country's diplomatic influence and promoting economic cooperation.

The evaluation methods for the above characteristics are introduced in Section V-C. The obtained evaluation values are used to select the candidate national image resources.

C. Key Constraints

To fully leverage the potential communication value of national image resources, some constraints need to be satisfied during the resource recommendation process. Otherwise, the communication effect of these resources may not be guaranteed. The constraints are as follows.

1) Recommendation Conflicts Between National Image Resources and Communication Audiences: The content contained within a national image resource may conflict with the culture of certain communication audiences. It is important to avoid a culture clash among audiences caused by the recommended national image resources. Otherwise, not only can the desired communication effect not be obtained, but it will lead to significant negative consequences.

2) Usage Frequency of National Image Resources: To ensure the diversity of recommendations and richness of communication content, the maximum of audiences that can be recommended for each national image resource must be set. The default value is 1 in this article.

3) Number of National Image Resources Involved in a Single Experience of a Communication Audience: If a national image promotional work contains an excessive number of resources, it can lead to audience fatigue. It will significantly reduce the communication effect. On the other hand, too few national image resources will cause that the communication content lacks richness and fail to leave a lasting impression on the audience. Thus, it is essential to evenly recommend national image resources to various communication audiences.

To facilitate the understanding, the terms are defined as the following symbols: A_i represents the ith national image resource; R_j is the jth communication audience; m represents the total number of selected national image resources; n is the total number of communication audiences; $C_{i,j}$ reflects whether there is a recommendation conflict between A_i and R_j, where $C_{i,j} = 0$ means A_i can be recommended to R_j and $C_{i,j} = 1$ means A_i cannot be recommended to R_j.

D. Basic Databases

Based on the evaluation models of national image resources and communication audiences, we built two basic databases, i.e., national image resource database and communication audience database. The national image resource database (see Appendix A.1 in the supplementary material) is responsible for organizing a vast array of heterogeneous national image resources, providing a centralized platform to facilitate resource querying, updating, and maintenance. Additionally, the data in the database needs to be regularly updated. The communication audience database (see Appendix A.2 in the supplementary material) can help us gain a deeper understanding of the characteristics of the communication audience and precisely recommend the national image resources by developing the personalized communication strategies. Based on them, it is more convenient for us to achieve the targeted international communication.

IV. Problem Statement

When a country is preparing to host an international event, such as the Olympic Games, an international tourism summit, or a poetry conference, the event organizer seeks to promote it worldwide. The goal of this promotion is to showcase a compelling national image, attract more participants and expand the global influence of the country. We assume that the keywords for this promotion and the list of communication audiences are the input data provided by the organizer. The collaborative recommendation of national image resources for targeted international communication is just to help organizers select the appropriate national image resources for different communication audiences. First, select adequate resources

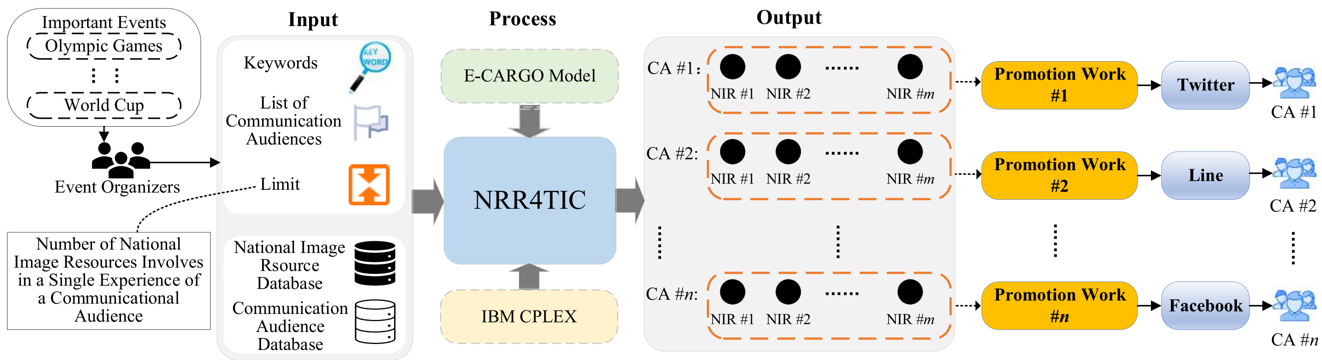

Fig. 3. National image resources recommendation problem description.

closely related to the keywords. Second, evaluate the compatibility between each resource and each audience. Third, the selected resources need to be recommended to different audiences according to compatibility, and each audience will receive a set of resources. A promotion work of national image is generated by arranging these resources. In fact, each audience ultimately receives a promotional work. Each promotional work will be sent to the most popular social media platforms for audiences. The national image resources recommendation problem is illustrated as Fig. 3. In Fig. 3, CA represents an audience and NIR represents a resource.

For example, in 2022, China hosted the Beijing Winter Olympics. To promote the spirit of the Winter Olympics to the world, i.e., "Focus on the Big Picture, Be Confident and Open, Face Challenges, Pursue Excellence, and Create the Future," we have chosen these keywords for promotion. Eventually, nine resources are selected from the national image resource database. Based on these resources, we need to create three promotional works of national image and recommend them to audiences from different countries, e.g., the United States, Japan, and India, by Twitter, Line, and Facebook, respectively.

The problem is analyzed in detail as follows.

1) Every communication audience R_j should be recommended at least one national image resource.
2) The importance of the features may be different for national image resources and communication audiences. For example, compared to D_1, D_2 better reflects the characteristics of a communication audience. Therefore, D_2 is more important than D_1 in personalized recommendations.
3) If the resource A_i has recommendation conflicts with most of the communication audiences, it is possible that the method described in this article may not yield an output. If no usable output is obtained in the end, another national image resource needs to be selected to replace the original A_i.
4) Based on a country's diplomatic priorities, the importance of different communication audiences can vary. For example, in the case of China, from a diplomatic perspective, the United States is likely to be more important than the Democratic Republic of Congo. Therefore, to ensure that more important communication audiences receive higher quality resources for more effective communication effect, high-quality national image resources will be prioritized for more important communication audiences.

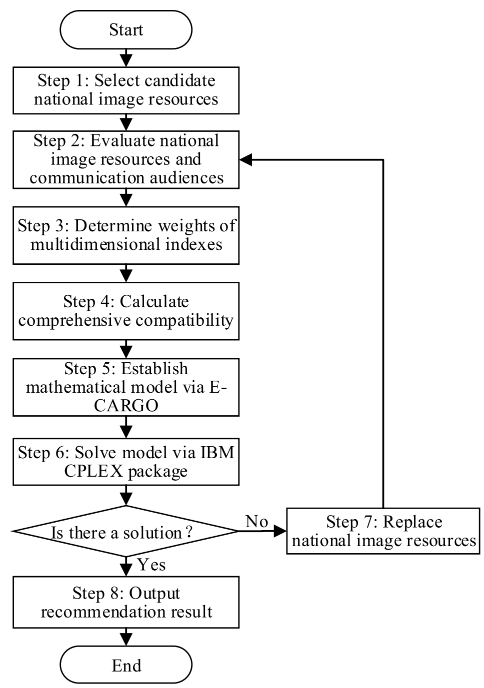

Fig. 4. Overall structure of NRR4TIC.

To sum up, in this problem, we need to discuss: 1) how to select m national image resources for n communication audiences? 2) how to quantify the compatibility between national image resources and communication audiences to ensure the desired communication effect? and 3) how to optimize the resource assignment scheme on the prerequisite of maximizing the comprehensive compatibility between m resources and n communication audiences, while both the resources and the audiences meet the constraints?

V. National Image Resources Recommendation

This article proposes a collaborative approach to national image resources recommendation for targeted international communication, denoted as NRR4TIC. The overall structure of NRR4TIC is shown in Fig. 4.

A. Select Candidate National Image Resources

Due to the vast number of resources in the national image resource database, it is not practical to utilize all of them. Therefore, it is necessary to select an adequate number of national image resources that best align with the promotional theme from the database. The steps for selecting candidate national image resources are as follows.

1) Use the Word2Vec algorithm to convert Words (i.e., the set of promotional keywords) and TagSet (i.e., the set of tags for all resources in the national image resource database) into word vectors. The TagSet consists of multiple tags, with every tag being converted into a separate word vector.
2) Extract the resource A_i, and calculate the similarity between Words and Tag_i^k (i.e., the kth tag in TagSet of A_i) by

$$\text{Sim}\left(\text{Tag}_i^k\right) = \sum_{x=1}^{x=X} \frac{\left(\text{Tag}_i^k \cdot \text{Words}_x\right)}{\left\|\text{Tag}_i^k\right\| \cdot \|\text{Words}_x\|} / X \tag{1}$$

where Words_x is the xth keyword in Words; X is the number of keywords in Words. Tag_i^k and Words_x are word vectors.
3) Calculate the similarity between A_i and Words. The similarity $\text{Sim}(A_i)$ is determined by

$$\text{Sim}(A_i) = \sum_{k=1}^{k=K} \text{Sim}\left(\text{Tag}_i^k\right) / K \tag{2}$$

where K denotes the number of tags in TagSet.
4) Repeat 2) and 3) to calculate the similarity between Words and all resources in national image resources database, and then select the top m resources with the highest similarity.

B. Evaluate National Image Resources

Suppose S^L and S^H are real numbers. Then, the interval number $S = [S^L, S^H]$ can be defined, where $0 \le S^L \le S^H \le 1$. S^L is the lower bound of S and S^H is the upper bound. When $S^L = S^H$, the interval number S reduces to a real number. Furthermore, real numbers and interval numbers can be converted between each other.

There are nine features in the evaluation model of national image resources. Among them, resources' values on $F_2 - F_7$ are scored by experts, and every value may be scored more than once. Thus, we use interval numbers to express them on $F_2 - F_7$.

The evaluation methods for nine features are as follows.

1) Evaluation Method for F_1: The value on F_1 is in the form of a string representing latitude and longitude coordinates, which is entered by the administrator of the national image resources database. Some resources have fictional background stories, so when identifying the associated location of them, we pinpoint the most accurate real-word location. For example, in the movie "Forrest Gump," the setting is a fictional town called Greenbow. While the town itself is fictional, it is located within the real state of Alabama. Therefore, the capital of Alabama would be set as the location, and its latitude and longitude coordinates would be saved. In this article, we assume that the national image resources are fine-grained, such as a short story or an ancient poem, and one resource is only associated with a country or region. If a resource occurs in multiple locations, we use the capital city of the country where these locations are located as the final location.

2) Evaluation Method for $F_2 - F_7$: The raw values on $F_2 - F_7$ are scored by domain experts, and every expert assigns a single real number $v (0 \le v \le 1)$ for a feature of a resource. Considering that the number of experts who score different resources is uncertain, a specific strategy is employed to determine the values on $F_2 - F_7$ referring to [20]. Taking F_2 of A_i as an example, the value on F_2 is represented as $V_i^2 = [V_i^{2L}, V_i^{2H}]$. V_i^2 is obtained as follows.

1) If there is only one raw value v on F_2, $V_i^2 = [v, v]$.
2) If the number of raw values is between 2 and 5, $V_i^2 = [v_1, v_2]$, where v_1 and v_2 represent the minimum and maximum original values, respectively.
3) If the number of raw values is more than 6, the cloud model is used to convert multiple values into a single interval number as the evaluation value on F_2. The steps are as follows.

Step 1: Assuming $T_{i2} = [v_1^{i2}, v_2^{i2}, \ldots, v_\delta^{i2}]$ is the set of score values from experts, where δ is the length of the set, the three numerical features of A_i on F_2 are calculated by

$$\begin{cases} C_i^{Ex} = \frac{1}{\delta} \cdot \sum_{t=1}^{\delta} v_t^{i2} \\ C_i^{En} = \sqrt{\frac{\pi}{2}} \cdot \frac{1}{\delta} \sum_{t=1}^{\delta} \left| v_t^{i2} - C_i^{Ex} \right| \\ C_i^{HE} = \sqrt{\left| \frac{1}{\delta - 1} \sum_{t=1}^{\delta} \left(v_t^{i2} - C_i^{Ex} \right)^2 - \left(C_i^{En} \right)^2 \right|} \end{cases} \tag{3}$$

where C_i^{Ex} is the expectation of T_{i2}, i.e., the most representative value of a qualitative concept; C_i^{En} is the entropy, i.e., an uncertainty measurement of T_{i2}; C_i^{HE} is the hyper entropy, which is an uncertainty measurement of C_i^{En}.

Step 2: The evaluation value of A_i on F_2 is determined by

$$\begin{cases} V_i^{2H} = C_i^{Ex} + C_i^{En} + C_i^{HE} \cdot \gamma \\ V_i^{2L} = C_i^{Ex} - C_i^{En} - C_i^{HE} \cdot \gamma \end{cases} \tag{4}$$

where γ represents the influence coefficient associated with C_i^{HE}, and it is set within a range of [0.1, 0.2] [27].

Likewise, we can calculate the evaluation values on $F_3 - F_7$.

3) Evaluation Method for F_8 and F_9: Once A_i has been recommended to R_j, R_j should be added to the evaluation value of A_i on F_8. After A_i has been recommended for one month, we will gather public evaluative texts of A_i from R_j. Then, we use the sentiment analysis techniques to analyze the text and generate a sentiment score. The score is added to the evaluation value of A_i on F_9. Each item in F_8 and F_9 should correspond one-to-one. It records which communication audience a resource has been recommended to and the communication effects in those communication audiences.

C. Evaluate Communication Audiences

The nine characteristics of communication audiences are stable and do not change significantly over time. Therefore, the evaluation for these characteristics can be conducted over an extended period of time. The evaluation methods for these characteristics are provided as follows.

1) Evaluation Method for D_1: The geographical location of the capital for each communication audience is identified by the database administrator.

2) Evaluation Method for $D_2 - D_7$: The evaluation values on $D_2 - D_7$ can be found at https://www.hofstede-insights.com/. This website provides measured values on the six characteristics for each communication audience. However, some values on certain characteristics of communication audiences are missing. In this case, the administrator can use the measurement tool in [28] to calculate measured values. The measured values on this website are real numbers ranging from 0 to 120, and we can normalize the measured values by

$$o_j^k = e_j^k / 120 \tag{5}$$

where e_j^k is the measured values (i.e., raw values) of R_j on D_k and o_j^k is the evaluation values (i.e., final values) of R_j on D_k.

3) Evaluation Method for D_8 and D_9: D_8 is evaluated by the database administrator based on the International Status Assessment Index System [29]. The level of alliance between the communication audience and the home country is determined by the administrator based on the home country's foreign policy. The value on D_9 is related to this alliance level and is an integer ranging from 0 to 10, where a higher value indicates a closer and more significant relationship.

D. Determine the Weights of Multidimensional Indexes

One national image resource or one communication audience is evaluated according to multiple features or characteristics. To aggregate multiple evaluation values, the weights of multiple indexes must be determined. Directly assigning feature weights manually might result in significant errors in the final comprehensive compatibility calculation because of subjective biases in human inherent perception. The fuzzy analytic hierarchy process (FAHP), combined with fuzzy logic, can reduce the influence of subjective factors and avoid challenges associated with large computational requirements and low precision. FAHP is suitable for addressing multifeature synthesis problems. Taking the evaluation model of national image resources as an example, the setting method of the feature weight is as follows.

Suppose there is a fuzzy judgment matrix $B = [b_{i,j}]_{\beta * \beta}$, satisfying $0 \leq b_{i,j} \leq 1$, where β is the number of features indicators of national image resources. $b_{i,j}$ represents the ratio of the importance of the ith feature indicator to the jth feature indicator. We determine $b_{i,j}$ ($i, j = 1, \ldots, \beta$) by employing the five-level complementary scales, which consists of 0.1, 0.3, 0.5, 0.7, and 0.9. If satisfying $b_{i,j} + b_{j,i} = 1$, $b_{i,i} = 0.5$, B is the fuzzy complementary judgment matrix. When B and k satisfy $b_{i,j} = b_{i,k} - b_{j,k} + 0.5$, B is the fuzzy consistency matrix and k is the kth feature indicator.

A fuzzy complementary matrix B is provided by experts. To transform B into a fuzzy consistency matrix, we should compute the sum of each row in B by (6) and conduct a mathematical transformation, which is shown as (7)

$$b_i = \sum_{k=1}^{\beta} b_{i,k} \tag{6}$$

$$z_{i,j} = \frac{b_i - b_j}{2(\beta - 1)} + 0.5. \tag{7}$$

The matrix $Z = (z_{i,j})_{\beta * \beta}$ is a fuzzy consistency matrix. In (6) and (7), $\beta = 9$. The sum of each row in Z is computed and subsequently standardized. Then, the weight w_k of the kth feature of national image resources is obtained by

$$w_k = \sum_{y=1}^{\beta} z_{k,y} + \frac{\beta}{2} - 1/\beta(\beta - 1). \tag{8}$$

Similarly, the weights for each characteristic of the communication audience can be determined.

E. Calculate the Comprehensive Compatibility

By comparing the similarities of features between national image resources and communication audiences, $Q_{i,j}$ is defined as a measure of the compatibility between A_i and R_j. A higher value indicates that A_i is more suitably recommended to R_j for leading to better promotional results. The distance between the associated locations of a resource and the capital locations of communication audiences should be as small as possible. The distance between A_i and R_j is obtained by

In (9), shown at the bottom of the page, $d_{i,j}$ is the distance, measured in kilometers; η is the average radius of the Earth (usually 6371 km); V_i^{LAT} and V_i^{LON} represent the longitude and latitude stored in value on F_1 of A_i; O_j^{LAT} and O_j^{LON} represent the longitude and latitude stored in value on D_1 of R_j, respectively.

The smaller the cultural differences between a national image resource and a communication audience, the more likely the audience is to accept the information conveyed in the national image resource. Thus, V_i^k (i.e., the value on the F_k of A_i) and O_j^k (i.e., the value on the D_k of R_j) should be as close as possible, satisfying $2 \leq k \leq 7$. We calculate the closeness between V_i^k and O_j^k based on the possibility degree of interval numbers. The closeness is named as $P_{i,j}^k$, and the possibility degree of interval numbers is calculated by

$$P_{1,2} = P(U_1 \geq U_2) = \frac{\min\{l_1 + l_2, \max\{u_1^H - u_2^L, 0\}\}}{l_1 + l_2} \tag{10}$$

$$d_{i,j} = 2 \cdot \eta \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{V_i^{\text{LAT}} - O_j^{\text{LAT}}}{2}\right) + \cos\left(V_i^{\text{LAT}}\right) \cdot \cos\left(O_j^{\text{LAT}}\right) \cdot \sin^2\left(\frac{V_i^{\text{LON}} - O_j^{\text{LON}}}{2}\right)}\right) \tag{9}$$

where $P_{1,2}$ is the possibility of $U_1 \geq U_2$; $U_1 = [u_1^L, u_1^H]$ and $U_2 = [u_2^L, u_2^H]$; $l_1 = u_1^H - u_1^L$ and $l_2 = u_2^H - u_2^L$. Due to o_j^k (i.e., the value on D_k of R_j) is a real number,we need to convert it to an interval number using the formula $O_j^k = [o_j^k, o_j^k]$.

The feedback can be collected after A_i is recommended to R_j. The feedback can provide insights into the acceptability of R_j for resources similar to A_i. If other resources similar to A_i have performed well after being recommended to R_j, it can be inferred that A_i is also likely to achieve good communication effect when recommended to R_j. The communication effect after A_i is recommended to R_j can be predicted by

$$S_{i,j} = \sum_{t=1}^{10} r_{i,j}^t / 10 \tag{11}$$

where $r_{i,j}^t$ represents the historical feedback score obtained by the resource with the tth highest similarity to A_i when it was recommended to R_j. A lager $S_{i,j}$ means that the communication effect is predicted to be better.

Get the comprehensive compatibility between A_i and R_j by

$$Q_{i,j} = w_1 \cdot \left(-\frac{d_{i,j}}{\partial}\right) + \sum_{k=2}^{7} w_k \cdot P_{i,j}^k + w_9 \cdot S_{i,j} \tag{12}$$

where w_k represents the weight of F_k and ∂ is the circumference of the Earth; ∂ is equal to 40075 in this article.

Based on the above calculation results, we can establish the problem model of national image resources recommendation and solve it. Section VI will introduce them in detail.

F. Complexity Analysis

From Fig. 4, steps 1–4 are the core operations of NRR4TIC. Thus, we analyze their complexity as follows.

1) The time complexity of step 1 is $O(M \times K \times X \times d + M \times \log M)$ and the space complexity is $O(M \times K \times d)$, where M is the number of resources in the national image resources database; K is the number of tags of each resource; X is the number of keywords in Words; and d is the number of dimensions of a word vector.
2) In step 2, the time and space complexity of evaluating national image resources are both $O(l)$, where l is the number of values from experts, while the time and space complexity of evaluating communication audiences are both $O(N)$, where N is the number of candidate audiences.
3) For step 3, the time complexity is $O(\beta^2)$ and the space complexity is $O(\beta^2)$, where β is the number of features.
4) The time and space complexity of step 4 are both $O(P \times N)$, where P is the number of selected resources; N is the number of candidate audiences. Considering that M is greater than P and much greater than l and β^2, and $\log M$ is greater than N, the overall time complexity of NRR4TIC is $O(M \times K \times X \times d + M \times \log M)$.

VI. Problem Modeling and Solving

A. Problem Modeling via E-CARGO

Based on the E-CARGO model [6], the collaborative recommendation problem of national image resources for targeted international communication is modeled as follows:

$$\sum ::= \langle E, C, O, R, A, G \rangle \tag{13}$$

where E represents the problem environment, which is a problem involving multiple national image resources and communication audiences; C is the set of classes that are used to represent abstract concepts; O is the set of concrete objects associated with C; R is the set of communication audiences for promoting national image resources; A is the set of selected national image resources; G is the set of national image resources, i.e., the resource groups formed according to the algorithm; G_j is the set of national image resources recommended to the jth communication audience.

The key components of the model are given as follows.

1) *Matrix Q:* It represents the compatibility between the national image resources and communication audiences. $Q_{i,j}$ is a measure of the compatibility between A_i and R_j by (12).
2) *Matrix T:* $T_{i,j} \in \{0, 1\}(0 \leq i < m, 0 \leq j < n)$. It represents whether A_i is recommended to R_j. $T_{i,j} = 1$ when A_i is recommended to R_j. $T_{i,j} = 0$ when A_i is not recommended to R_j.
3) *ρ:* It represents the total comprehensive compatibility of all the groups of national image resources. A larger ρ indicates that the compatibility between all the resources and their communication audiences will be higher, the communication value of these resources will be maximally utilized, and the communication effect will be better. For a resource recommendation task, it is necessary to maximize ρ to achieve a better communication effect for all resource groups.

According to the above definitions, the objective function of the problem in this article could be defined by

$$\max \rho = \sum_{i=1}^{m} \sum_{j=1}^{n} Q_{i,j} \times T_{i,j} \tag{14}$$

where m represents the number of selected national image resources; n represents the number of communication audiences for promoting resources. $T_{i,j}$ should meet the following constraints:

$$\sum_{j=1}^{n} C_{i,j} \cdot T_{i,j} = 0, 1 \leq i \leq m \tag{15}$$

$$\sum_{j=1}^{n} T_{i,j} \leq 1, 1 \leq i \leq m \tag{16}$$

$$\sum_{i=1}^{m} T_{i,j} = L_j, 1 \leq j \leq n. \tag{17}$$

Equation (15) represents that $T_{i,j}$ must not have any recommendation conflicts. Inequality (16) represents that each national image resource can be recommended to only one communication audience at most. Equation (17) represents the constraint on the number of national image resources that each communication audience will be recommended. In (17), $L_j \geq 1$ represents the number of national image resources acquired by the jth communication audience.

B. Problem-Solving via CPLEX

The maximum of the objective function (14) is obtained via the IBM CPLEX optimization package. To solve linear programming problems, CPLEX uses some optimizers, such as Simplex Optimizers and Barrier Optimizer. These optimizers have proven to be efficient in practice for identifying the convergent optimal solution. The solution process is provided as follows.

Step 1: Determine the weight of national image resources' features, according to the FAHP method.

Step 2: Evaluate the national image resources, according to the evaluation methods in Section V-A.

Step 3: Evaluate the communication audiences, according to the evaluation methods in Section V-B.

Step 4: Calculate the compatibility matrix Q between national image resources and communication audiences.

Step 5: Determine the core data structure of the CPLEX interface. CPLEX requires input parameters, such as objective function coefficients, constraint coefficients, upper bounds, and lower bounds. The linear programming problem in CPLEX is defined by using Q, L, and T, where Q is the objective function coefficients and T expresses the variables.

Step 6: Preadjust the values in Q by using the matrix C. The formula is $Q_{i,j} = Q_{i,j} \cdot C_{i,j}$.

Step 7: Set the constraint expressions and the objective function. The objective function of this problem consists of three matrices: Q, T, and C. First, define the decision variable T:mdl = docplex.mp.model.Model();T_vars = {(i, j):mdl.binary_var(name = "T_{0}_{1}."format(i, j)) for i in range(0, m) for j in range(0, n)}. Then, add the constraint conditions. Finally, add the optimization objective by calling the following method: objective = mdl.sum(T_vars[i, j] * Q[i, j] for i in range(0, m) for j in range(0, n)); mdl.maximize(objective).

Step 8: Use the docplex.mp.model.solve() method of CPLEX to solve T. The maximum value of ρ and corresponding T are obtained on the premise that T satisfies the constraint expressions.

VII. Case Study

A. Case of National Image Resources Recommendation

To promote the 19th Asian Games, which will take place in Hangzhou in September 2023, the conference organizers provided the keywords: "Green, Intelligent, Thrifty and Civilized." At the same time, the organizers have identified five countries shown in Table I as the key focus for promotion. The communication audiences can be denoted as $R = \{r_0, r_1, \ldots, r_4\}$. The remaining settings will be set to the system default. With the NRR4TIC, we initially extract 12 resources from the national image resources database based on the provided keywords. These candidate resources are shown in Table II and can be represented as $A = \{a_0, a_1, \ldots, a_{11}\}$.

Then, after calculating the compatibility between each resource and each audience, a resources group is recommended to each audience by an optimization solution.

TABLE I
Candidate Communication Audiences

Index	Communication audience
r_0	Japan
r_1	the United States
r_2	Russia
r_3	India
r_4	France

TABLE II
Candidate Resources

Index	Resource
a_0	The image of the medals for Hangzhou Asian Games
a_1	A photo of Hangzhou Asian Games Football Stadium
a_2	A promotional video showcasing Hangzhou's scenery
a_3	An introductory video of "Smart Asian Games One-Stop Pass" application which is a One-stop Digital Sports Viewing Service Platform
a_4	An aerial video of Hangzhou Esports Center
a_5	An aerial video of Fuyang Yinhu Sports Center
a_6	The image of Asian Games Emblem
a_7	A promotional video showcasing Hangzhou's cuisine
a_8	One of the promotional songs for Hangzhou Asian Games called "To Win"
a_9	One of the seven promotional songs for Hangzhou Asian Games called "The Love We Share"
a_{10}	An aerial video of Hangzhou Olympic Sports Center Stadium
a_{11}	A promotional video featuring the mascot of Hangzhou Asian Games

TABLE III
Resource Recommendation Results

Communication audience	Set of national image resources
r_0	a_6, a_{10}
r_1	a_1, a_8, a_{11}
r_2	a_0, a_4
r_3	a_9
r_4	a_7

Suppose the weight vector of features of national image resources calculated by the FAHP method is $W = [0.0861, 0.1127, 0.1127, 0.1127, 0.1127, 0.1127, 0.1127, 0.1142, 0.1236]$, $L = [2, 3, 2, 1, 1]$. The conflicts matrix C is provided as Fig. 5(a). The original values for the resources in set A are scored by domain experts and converted into interval numerical values. Features values of candidate resources are shown in Appendix A.3 in the supplementary material. Then, extract the important columns of the five audiences from the communication audience database, as shown in Appendix A.3 in the supplementary material.

We calculate the matrix Q by (9)–(12) and the matrix T is obtained as Fig. 5(b) with the CPLEX optimization package. The calculation process of Q is discussed in Appendix A.4 in the supplementary material, and the calculated Q is shown in Fig. 5(c). Based on T, the recommended resources are obtained for communication audiences, as shown in Table III. With the NRR4TIC, the maximum value of the objective function is 11.918.

B. Results Analysis

By analyzing Table III, the recommendation results are reasonable, which could be explained as follows.

1) r_0: a_6 symbolizing the core characteristics of emphasizing intrinsic value, natural beauty, and peace and a_{10}

$$C=\begin{bmatrix}1&0&0&1&0\\0&0&0&0&1\\1&1&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&1&0&0\\0&0&0&1&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&0&0&0\end{bmatrix}$$

(a)

$$T=\begin{bmatrix}0&0&1&0&0\\0&1&0&0&0\\0&0&0&0&0\\0&0&0&0&0\\0&0&1&0&0\\0&0&0&0&0\\1&0&0&0&0\\0&0&0&0&1\\0&1&0&0&0\\0&0&0&1&0\\1&0&0&0&0\\0&1&0&0&0\end{bmatrix}$$

(b)

$$Q=\begin{bmatrix}0.9982&0.5802&1.3862&0.3356&0.2449\\0.0010&0.9128&1.1570&0.9567&0.5061\\0.9812&1.3855&0.9933&0.5200&0.4733\\1.1145&0.4372&1.2914&0.933&0.7923\\0.3269&0.8278&1.5369&0.4997&0.3055\\0.4444&0.2995&11028&0.5520&1.1007\\1.2712&0.5952&0.3882&1.1381&0.1659\\11843&0.8580&1.3168&0.5513&1.2786\\1.3132&1.3108&0.8748&0.4380&1.1999\\1.0367&0.8420&0.7569&15370&0.8162\\1.4631&0.3921&0.8424&1.5277&0.4393\\0.4986&1.2218&0.3936&1.4469&0.4279\end{bmatrix}$$

(c)

Fig. 5. Three matrices. (a) Matrix C. (b) Matrix T. (c) Matrix Q.

reflecting the theme of loving sports are in line with the cultural characteristics of Japan.

2) r_1: First, a_1 is recommended to r_1, because American football is regarded as one of the major national sports in the United States, which reflects American values like teamwork, competition, and perseverance. Second, a_8 conveys the belief in pursuing victory and excellence, which aligns with American culture. Third, while a_{11} represents the natural ecology of Hangzhou, including the beautiful West Lake, the United States also boasts various natural landscapes, including national parks, lakes, and mountains. Natural landscapes hold a special place in American culture.
3) r_2: Showcasing a_0 to the Russians can evoke their national pride, known for their resilience, tenacity, and unwavering spirit. Besides, Russia has distinct characteristics in esports, and there are world-renowned clubs in Russia. Therefore, a_4 is recommended to Russia.
4) r_3: a_9 is presented in the form of song and dance. India has a rich and diverse tradition of dance and music, which play an extremely important role in Indian culture.
5) r_4: France is famous for its exquisite cooking, and the French consider food a part of their daily lives. Therefore, a_7 is recommended to France.

C. Creating Promotional Works of National Image

After generating the recommendation solution in Section VII-A, it is necessary to create complete national image promotional works using the recommended resources for different communication audiences. The construction scheme used in this article for these works is as follows.

1) Extract the tag sets and remarks of the recommended resources from the national image resource database.
2) Input these tag sets and the names of the communication audiences into ChatGPT in a fixed format. Based on this information, ChatGPT will generate national image promotion manuscripts.
3) Combine the promotion manuscript with the national image resources to create the promotional works of national image.

Take the United States as an example, we present the promotion manuscript and the final national image promotional work in Appendix A.5 in the supplementary material. All the promotional works of national image mentioned in Section VII-A are available at https://github.com/Will-xc/NRR4TIC.

VIII. Simulation Experiments

To verify the validity of NRR4TIC, simulation data is employed for experimental analysis, and experiments are conducted to answer the following research questions (RQs).

1) *RQ1:* How about the efficiency of data preprocessing in NRR4TIC?
2) *RQ2:* How about the efficiency of NRR4TIC compared with the existing approaches?
3) *RQ3:* How about the performance of NRR4TIC from the perspectives of accuracy and objective function values compared with existing approaches?

To the best of our knowledge, there is no existing research that is identical to the problem scenario and modeling approach used in this article. Thus, referring to [19] and [30] on E-CARGO, two classical algorithms, i.e., exhaust algorithm (EA) and greedy algorithm (GA), are selected as the baseline approaches. EA explores all feasible methods in an exhausting manner to find the optimal solution for the national image resources recommendation problem, and GA exhibits superior execution efficiency and can obtain suboptimal results for problems with large sizes.

The experiments are executed within the PyCharm IDE on a 64-bit Windows 11 operating system, utilizing an Intel Core i5-13500H CPU operating at a clock speed of 2.60 GHz and 32 GB of memory. The code is written in Python. The parameters used in experiments are set as follows: 1) the influence coefficient γ in (4) is set as 0.15 [27]; 2) the conflicts probability p is set to be 0.1–0.4; in practice, 40% is already quite a high probability; 3) considering the computational limits of the EA, in the experiments about RQ2 and RQ3, we set m to be 8–26 with a step size of 2; and 4) n is tested in two cases, i.e., $n = \lfloor m/3 \rfloor$ and $n = \lfloor m/4 \rfloor$.

A. Analysis of Data Preprocessing Time (RQ1)

First, we must collect data, such as original values from domain experts for the resources, accessed values about communication audiences, and transform them into interval numbers. Second, calculate the possibility degree of features on the different dimension between them. Third, compute

TABLE IV
EXECUTION TIME (MILLISECOND)

m		8	10	12	14	16	18	20	22	24	26
$n=\lfloor m/4 \rfloor$	NRR4TIC	5.08	5.44	6.10	6.22	6.67	6.73	6.80	7.20	7.72	8.01
	GM	0.12	0.15	0.19	0.20	0.33	0.35	0.41	0.60	0.61	0.64
	EA	7.02	37.14	2572.89	24166.97	N/A	N/A	N/A	N/A	N/A	N/A
$n=\lfloor m/3 \rfloor$	NRR4TIC	4.69	5.24	5.82	5.63	6.17	6.24	6.57	6.97	7.33	7.81
	GM	0.12	0.13	0.18	0.19	0.24	0.46	0.47	0.49	0.52	0.75
	EA	4.84	86.20	3333.58	13826.40	N/A	N/A	N/A	N/A	N/A	N/A

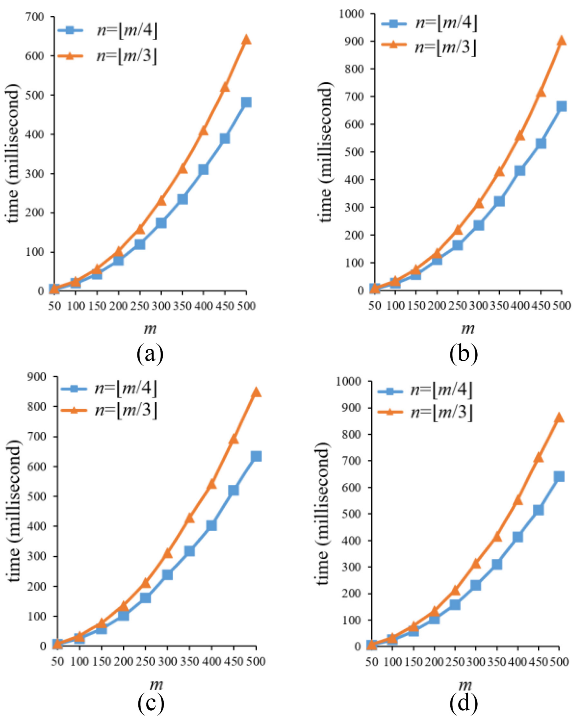

Fig. 6. Analysis of data preprocessing time. (a) $p = 0.1$. (b) $p = 0.2$. (c) $p = 0.3$. (d) $p = 0.4$.

the actual distance between resources and the communication audiences. Fourth, calculate the predicted values of communication effect for each resource. Finally, compute the comprehensive compatibility matrix Q.

To evaluate the time consumption of the above data preprocessing process, we set m to be 50–500, step size to be 50, and repeated the experiment 50 times to obtain the average results. The experimental results are shown in Fig. 6.

Fig. 6 shows that with the increase in the number of national image resources and communication audiences, the time consumption for data preprocessing exhibits a gradual increment, and this increment appears to follow an almost linear trend. For the largest data scale with 500 national image resources and 166 communication audiences, the data preprocessing time for the NRR4TIC is below 0.91 s.

B. Analysis of Execution Time (RQ2)

In the experiments, Q, C, and L are initialized in each step of m. The execution time of NRR4TIC is compared with the greedy method (GM) and the EA. The results are shown in Table IV.

TABLE V
ACCURACY ANALYSIS

m		6	8	10	12	14
p=0.1	NRR4TIC	1	1	1	1	1
	GM	0.985	0.983	0.990	0.994	0.993
p=0.2	NRR4TIC	1	1	1	1	1
	GM	0.978	0.988	0.989	0.984	0.987
p=0.3	NRR4TIC	1	1	1	1	1
	GM	0.975	0.979	0.981	0.986	0.969
p=0.4	NRR4TIC	1	1	1	1	1
	GM	0.955	0.963	0.969	0.974	0.909

Here, the notation “N/A” signifies that the optimal solution is obtained beyond 30 min. Table IV shows that as the number of national image resources grows, there is a notable increase in the execution time of three algorithms. Specifically, the processing time of EA exhibits exponential growth.

C. Accuracy Analysis (RQ3)

The experiments use EA as the baseline to measure the accuracy of other methods. According to the results in Section VIII-B, the optimal solution cannot be obtained by EA in 30 min when m is greater than 14. Thus, we set the number of audiences as $\lfloor m/3 \rfloor$, and the number of resources from 6 to 14 with a step size of 2 and conducted 50 repeated experiments.

The solving accuracy is calculated as follows:

$$\text{accuracy} = 1 - \left(\rho^* - \rho\right)/\rho^* \tag{18}$$

where ρ^* is the optimal objective function value acquired through EA; ρ is the objective function value obtained by other methods. The results are presented in Table V, which demonstrates that NRR4TIC could consistently obtain the optimal solution for big data sizes, with an accuracy value of 1. Although GM has high performance, it cannot always guarantee the optimal solution. Especially when the conflict probability is high, the accuracy of GM is obviously not ideal.

D. Analysis of Objective Function Values (RQ3)

We compare the objective function values of the proposed algorithm and GM in different recommendation conflict probabilities. The experimental findings are presented in Table VI, which demonstrates that NRR4TIC outperforms GM in terms of the objective function value. To measure the numerical

TABLE VI
OBJECTIVE FUNCTION VALUES

m			8	10	12	14	16	18	20	22	24	26
$n=\lfloor m/4 \rfloor$	p=0.1	NRR4TIC	**3.865**	**8.542**	**10.560**	**9.379**	**10.300**	**16.369**	**12.101**	**14.135**	**14.454**	**19.617**
		GM	3.851	8.542	9.367	9.379	10.300	15.953	11.586	14.135	14.367	19.456
	p=0.2	NRR4TIC	**5.450**	**2.760**	**4.347**	**10.386**	**9.639**	**13.147**	**13.841**	**16.769**	**15.336**	**24.753**
		GM	5.450	2.760	4.347	9.728	9.370	13.147	13.841	16.609	14.975	23.886
	p=0.3	NRR4TIC	**4.791**	**5.908**	**10.158**	**7.502**	**11.356**	**8.065**	**17.002**	**12.759**	**14.652**	**20.963**
		GM	4.790	5.908	9.513	6.896	10.947	8.065	16.385	12.759	14.535	20.963
	p=0.4	NRR4TIC	**6.646**	**3.633**	**7.064**	**13.295**	**13.757**	**14.427**	**13.536**	**18.789**	**17.348**	**10.916**
		GM	6.646	3.633	7.064	12.629	13.223	14.427	13.429	18.355	16.467	10.899
$n=\lfloor m/3 \rfloor$	p=0.1	NRR4TIC	**6.513**	**5.048**	**6.936**	**4.991**	**11.478**	**13.835**	**11.469**	**14.927**	**15.161**	**15.226**
		GM	6.513	5.048	6.936	4.758	11.478	13.467	11.263	14.896	14.896	15.226
	p=0.2	NRR4TIC	**4.088**	**4.467**	**6.279**	**6.599**	**10.829**	**11.264**	**14.421**	**17.787**	**19.101**	**20.150**
		GM	4.088	4.467	6.005	6.332	10.829	11.264	14.030	17.608	18.917	19.145
	p=0.3	NRR4TIC	**2.899**	**5.538**	**6.298**	**7.001**	**11.492**	**14.067**	**9.774**	**14.167**	**14.448**	**17.183**
		GM	2.899	5.273	6.298	6.403	11.286	14.067	9.774	14.167	14.382	16.890
	p=0.4	NRR4TIC	**3.578**	**5.013**	**7.266**	**7.960**	**10.468**	**10.942**	**10.789**	**14.216**	**16.880**	**20.461**
		GM	3.578	5.013	7.266	7.960	10.468	10.836	10.465	13.337	16.265	20.204

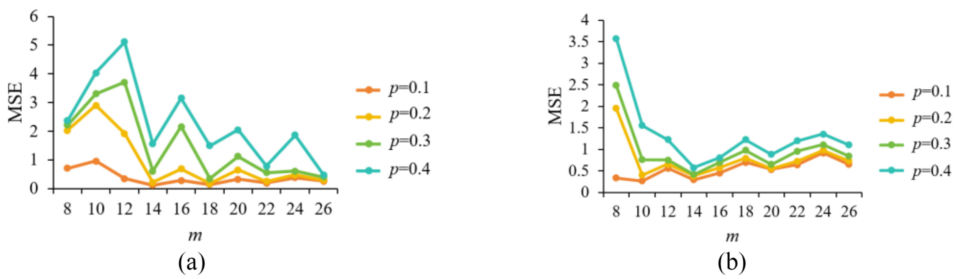

Fig. 7. MSEs in different conflict probabilities.(a) $n = \lfloor m/4 \rfloor$. (b) $n = \lfloor m/3 \rfloor$.

deviation of the objective function between GM and the proposed method, the mean-square error is calculated by

$$\text{MSE} = \sum_{k=1}^{50} (y - \widehat{y})^2/50 \quad (19)$$

where y is the objective function value obtained by GM, $\widehat{y}$ is the objective function value obtained by NIRR4TIC; 50 means that we generate 50 simulation data for each p and each m.

From Table V, NIRR4TIC can always obtain the optimal solution like EA. Thus, in (19), we only compare GM and our method. The results are shown in Fig. 7. From Fig. 7, with the increase of p, the MSE values of objective function between GM and NRR4TIC increases significantly, which indicates that the deviation between the objective function value obtained by GM and real value keeps increasing.

IX. CONCLUSION

This study offers important theoretical contributions by introducing the RBC theory and E-CARGO model to solve the national image resources recommendation problem. A novel approach named NRR4TIC are proposed. We construct two evaluation models to analyze resources and audiences, respectively. Three types of constraints are defined to reduce potential conflicts from cultural differences between resources and audiences. This study provides a new research paradigm of the national image resources recommendation problem for targeted international communication.

In summary, the advantageous capability of NIRR4TIC in national image resources recommendation can offer practical implications in the context of increasingly fierce international competition. Besides, NIRR4TIC can serve as an effective tool for managers, such as governments and event organizers. The managers can rely on NIRR4TIC to recommend the most appropriate national image resources to the communication audiences based on their characteristics. Thus, NIRR4TIC could improve the efficiency of building a national image and the effectiveness of international communication.

In the future, we will further explore strategies for the intelligent generation of promotional works of national image, use deep learning technology to improve our approach based on real-world data about national image resources, and more accurately evaluate national image resources and communication audiences.

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