

Digital Empowerment for the Development of Cultural Tourism Resources in Heilongjiang Based on Cultural Narrative Value Evaluation A Study on Utilization Efficiency Improvement and Tourist Experience Optimization

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ABSTRACT Heilongjiang Province has rich cultural and tourism resources, but their development is constrained by fragmented cultural narratives, low resource utilization efficiency, and homogenized tourist experiences. To address these problems, this study constructs a cultural narrative value evaluation index system and proposes a digital empowerment path for cultural tourism resource development. First, cultural narrative value is evaluated through a multidimensional index system. Second, digital technology is used to mine and integrate narrative elements, while a data envelopment analysis model is constructed to assess resource utilization efficiency. Third, tourist behavior trajectories and sentiment data are collected to identify experiential needs and optimization points. Finally, targeted digital empowerment strategies are designed based on the evaluation results. Empirical findings show that the average resource utilization efficiency of cultural tourism projects increased by 18.7%, the number of data-envelopment-analysis-effective projects increased significantly, tourist visitation of narrative nodes increased by 25.2%, and the positive sentiment rate increased by 26.5 %. The results confirm that digital technology can improve narrative transformation efficiency and tourist experience quality.

INDEX TERMS cultural tourism resources, digital empowerment, cultural narrative value, data envelopment analysis, tourist experience

I. INTRODUCTION

HEILONGJIANG Province possesses excellent cultural and tourism resources, yet its development remains constrained by shallow narratives and low utilization of historical assets, including the neglected heritage of its traditional industry. This lack of integration for weaving craftsmanship and industrial sites results in uniform tourist experiences that restrict the deep conversion of unique cultural values and hinder the overall competitiveness of the region's tourism industry [1,2]. Therefore, exploring how to reconstruct the development paradigm through systematic and digital means to achieve a transformation from resource-driven to value-driven development has important theoretical significance and practical urgency [3]. Existing research focuses on the qualitative interpretation of the cultural value of cultural and tourism resources or the macro-analysis of the

impact of tourism economy. For example, Tang et al. used 16 typical traditional villages in Beijing as cases to propose an evaluation system and influencing factor model for the integration of traditional village culture and tourism [4]. Rahman et al., starting from stakeholder theory, emphasized the core role of social capital and cultural capital in tourism destination governance [5]. Kastenholz and Gronau explored the role of higher education in enhancing students' ability to participate in the co-creation of cultural heritage, and analyzed the challenges faced in improving tourism and heritage management courses through surveys and interviews [6]. Amoako et al. used semi-structured interviews and qualitative methods, based on stakeholder theory and resource-based theory, to analyze the impact of stakeholder perspectives on business sustainability in the tourism industry of Ghana and Africa [7]. However, these methods are often

fragmented and fail to construct a closed-loop research path from "narrative value evaluation" to "resource allocation optimization" and then to "experience effect verification". This paper innovatively proposes an integrated framework: firstly, a quantitative narrative value evaluation system is constructed, and then the DEA model is used as the key output indicator to measure the utilization efficiency. At the same time, multi-source behavioral and emotional data are combined to accurately evaluate the experience effect, thereby systematically responding to the core question of "how to scientifically evaluate and effectively transform the cultural narrative value of cultural tourism resources" [8]. This study aims to solve the problems of inefficient cultural narrative transformation and insufficient tourist experience optimization in the development of cultural tourism resources in Heilongjiang through digital empowerment. To achieve this goal, the study comprehensively uses cultural narrative theory, data envelopment analysis (DEA), and multi-source data mining methods. The specific steps are: firstly, a multi-dimensional evaluation index system of cultural narrative value is constructed; then, the resource utilization efficiency is quantitatively analyzed using the DEA model; at the same time, the experience optimization effect is empirically tested by collecting tourist trajectory and emotional data. Ultimately, the study formed a three-in-one methodology path of "value evaluation - efficiency diagnosis - experience optimization". Empirical results show that this path can effectively improve resource allocation efficiency and tourist experience quality by integrating traditional craftsmanship into the digital cultural tourism framework. This approach provides an operable theoretical and practical solution for high-quality development, ensuring that the preservation of weaving heritage and industrial sites becomes a core driver of cultural resource optimization [9].

II. CONSTRUCTION OF A CULTURAL NARRATIVE VALUE EVALUATION SYSTEM

Addressing the problem that Heilongjiang's cultural tourism resources still rely on qualitative description and lack systematic quantitative evaluation standards for cultural narrative value, this paper aims to build a multi-dimensional and applicable evaluation framework. The construction proceeds logically in the order of "theme refinement - dimensional deconstruction - indicator quantification - weight determination.". Firstly, the vertical axis of narrative theme is established. Based on tracing the background of cultural context of Heilongjiang, this paper constructs four levels of core narrative themes of Heilongjiang's cultural tourism, namely, "Northern Frontier Epic and the Integration of Diverse Civilizations", "Ice and Snow Ecological Aesthetics", "Red Spirit and Industrialization Process", and "Ethnic Minority Customs and Traditional Life Wisdom", so as to clarify the value orientation and content scope of evaluation. Second, it establishes a multi-dimensional evaluation criterion layer. To comprehensively measure narrative value, the system is deconstructed from four key dimensions:

- (1) Historical authenticity and cultural representativeness: examining the credibility of the historical information carried by the resources and their iconic status in the regional cultural spectrum.
 - (2) Artistic appeal and aesthetic uniqueness: assessing the impact and recognizability of the resources in terms of expression, artistic achievement and landscape aesthetics.
 - (3) Narrative extensibility and experience carrying capacity: measuring the depth of its story, its potential for integration with the modern context, and the spatial and content foundation supporting interactive experiences.
 - (4) Communication influence and market awareness: judging the breadth and effectiveness of its value dissemination through existing media exposure, brand awareness and potential audience size [10].
- Next, according to the above analysis, we construct the specific measurable indicator layers and determine the indicator weights. Under each dimension, we refine the secondary indicators that can be observed and collected. For example, under the dimension of "communication influence", we set "growth rate of social media mentions" and "brand logo recognition rate". The determination of indicator weights applied Delphi expert consultation method and the Analytic Hierarchy Process (AHP) in this study. Experts from related fields, such as cultural heritage, tourism management and communication, were invited to score back-to-back in multiple rounds. After the consistency test, the weight set reflecting the relative importance of each indicator was obtained at last. In this way, the qualitative judgment was transformed into a basis for quantitative analysis. Therefore, a complete cultural narrative value evaluation indicator system was constructed, the core components of which are shown in Table 1. This system deconstructs abstract cultural values into observable and quantifiable specific indicators, and assigns each indicator a scientifically calculated weight.

Finally, a comprehensive scoring model was developed and validated through examples. The aforementioned themes, dimensions, indicators, and weights were integrated to construct a linear weighted comprehensive evaluation function.

III. ANALYSIS AND INTEGRATION OF DIGITAL NARRATIVE ELEMENTS OF CULTURAL AND TOURISM RESOURCES

Following the construction of the cultural narrative value evaluation system, this section explains how digital technology is used to deeply analyze narrative elements and systematically integrate them for utilizing Heilongjiang's cultural tourism resources. The analysis process can be divided into data collection and organization. We extensively collected multi-modal data for target resources. The text part includes local chronicle, historical archive, academic books and literature, folk legend, etc. The visual part includes historical map, cultural relic picture and landscape picture, while the feedback part includes tourists' comment and social media, etc. Finally, we used natural language processing

TABLE 1. Examples of Cultural Narrative Value Evaluation Indicators and Weights

Objective Layer	Criterion Layer	Weight	Indicator Layer (Examples)
Cultural Narrative Value	Historical Authenticity	0.3	Number of Documented Historical Events, Cultural Relic Protection Level
	Artistic Appeal	0.25	Number of Unique Visual Symbols, Scarcity of Art Form
	Narrative Extensibility	0.25	Number of Developable Storylines, Proportion of Interactive Space
	Communication Influence	0.2	Growth Rate of Social Media Mentions, Brand Recognition Rate

technology to realize entity recognition, relation extraction and sentiment analysis on text data, and automatically mined main persons, historical events, cultural icons, location and other narrative entities and their relationships to form initial “narrative knowledge elements” [11]. Furthermore, the narrative space was positioned and presented based on GIS. The analyzed narrative entities were geocoded accurately and overlaid with existing spatial layers, including cultural relic sites, scenic area boundaries and infrastructure. Based on the spatiotemporal GIS analysis, the spatial distribution of individual narrative spaces can be visualized, and the narrative clusters and linear threads can also be discovered, which assembles scattered cultural points into a “narrative map” with logical and emotional tension and shows its spatial narrative structure. Finally, the relational knowledge graph is constructed to achieve intelligent integration. In order to break the information isolation, the narrative entities, attributes, spatiotemporal tags and interrelationship extracted and labeled in the above two steps are imported into graph database in the form of “entity-relationship-entity” triplet and used to construct the relational knowledge graph of Heilongjiang cultural tourism narratives. This graph can dynamically show the implicit connection of different resources in terms of theme, characters and spatiotemporal information and integrate scattered narrative information into an integrated network of meaning.

IV. RESOURCE UTILIZATION EFFICIENCY DIAGNOSIS BASED ON DATA ENVELOPMENT ANALYSIS

This section applies the DEA model to conduct objective diagnosis and quantitative comparative analysis of resource utilization efficiency across cultural tourism projects. It is needed to explain that the operation of cultural tourism project is generally a situation of variable returns to scale, so the input-oriented BCC model is selected for efficiency evaluation. The selection of input and output indicators is crucial for effective diagnosis. On the input side, three quantifiable economic indicators are selected as input items, including “capital input (annual operating and development costs)”, “human resources (number of management and service personnel)” and “facility maintenance costs”. On the output side, comprehensive score of cultural narrative value constructed in the previous chapter is selected as one of output indicators, and “annual tourist arrivals” as market-based output indicator. This design allows the abstract effect of cultural value transformation to enter into the efficiency indicator, and makes the analysis simultaneously considers the economic efficiency and cultural effectiveness of the

project. Each cultural tourism project is treated as a DMU and then comprehensive technical efficiency (TE), pure technical efficiency (PTE) and scale efficiency (SE) of DMU are calculated by DEA model. The relative distance between unit and “efficiency frontier” formed by all optimal units is measured by overall technical efficiency (θ). If $\theta=1$, it means that the unit is on the frontier and has reached the optimal state of input and output combination; if $\theta<1$, there will be efficiency loss. By comparing the change of various projects’ efficiency value of before and after digital empowerment, the efficiency improvement effect brought about by empowerment measures can be directly quantified. The advantage of DEA model is not limited to providing efficiency scores, but also providing the improvement information. For the unit that is not DEA effective, model can calculate the “input slack” and “output shortfall” of each input of the unit. This kind of diagnosis is accurate to the level of individual indicators, making the general judgment of causes of unit’s inefficiency becomes clear definitions of “which input is redundant” or “which output is insufficient”. Therefore, the model provides direct and quantifiable basis for making decisions in the subsequent targeted optimization strategies, that is, reduce the surplus marketing expenditure or enhance the digital expression of certain narrative content.

V. VISITOR EXPERIENCE DATA PERCEPTION AND OPTIMIZATION STRATEGY GENERATION

In this study, we built a data collection network at the experience lifecycle level. At the physical space level, low-power Bluetooth beacons, Wi-Fi probes, and environmental sensors were used to collect tourists’ spatiotemporal trajectories, dwell time, route choices, and local crowd density unobtrusively. At the digital space level, web crawling technology was used to collect real-time reviews and images published on social media and tourism websites of the target scenic area. At the same time, electronic questionnaires with structured questions were distributed at critical points (such as exits and rest areas) to collect tourists’ satisfaction ratings and revisit intentions. These three types of data, namely, behavioral logs, emotional texts, and attitude ratings, collectively form a multidimensional tourists’ experience profile. After cleaning and merging the heterogeneous data collected from these three sources, we used several analytical methods to extract useful information. First, we used cluster analysis to segment tourists into subgroups with different behavioral patterns (such as “deep cultural exploration” and “quick sightseeing”) and emotional characteristics (such as “highly interactive and positive” and “negative and complaining”).

Second, by using association rule mining (such as the Apriori algorithm), we analyzed the typical behavioral sequences of highly satisfied visitors [such as (“after spending 15 min in exhibition area A, go to interactive installation B”)], discovering the key paths and element combinations that lead to a high-quality experience. More important, by using natural language processing to conduct fine-grained sentiment analysis and topic modeling of review texts, we can accurately locate to the specific points or service deficiencies that cause negative emotions [such as “the explanation of a certain history is so boring” “getting lost due to ambiguous signage”], reaching a more precise understanding of the cause of “overall dissatisfaction” from the perspective of “specific problem points.”. Based on the above analysis, hierarchical optimization strategies are generated. At the individual, real-time level, a recommendation engine was designed to push personalized tour routes and in-depth narrative content to visitors’ mobile phones based on their initial behavior patterns. However, it should be noted that this feature remains a design proposal awaiting full implementation; empirical data on user adoption rates, such as the percentage of visitors who downloaded the necessary application or actively engaged with push notifications, have not yet been collected. This constitutes a limitation of the current study, as the effectiveness of the recommendation mechanism cannot be empirically verified without measuring actual user engagement. Future research should prioritize the collection of user interaction data to validate the real-world impact of such personalized digital interventions on visitor experience. At the operational management level, optimization instructions are generated: based on the hotspot-blind spot analysis map, the layout of guide signs or staff allocation is adjusted; based on the sentiment analysis report, the explanations are revised or the service aspects that trigger complaints are modified. At the long-term planning level, it provides decision support: preference data and high-satisfaction routes for each segmented group provide precise demand basis for the development of future new products and routes. This process forms a continuous iterative closed loop of “perception-analysis-optimization-reperception”, transforming tourist experience management from a vague art relying on experience to a precise science based on data feedback.

VI. VALIDATION OF EFFICIENCY AND VISITOR EXPERIENCE OPTIMIZATION

A. OVERALL EXPERIMENTAL SETUP

This study employs a hybrid experimental design combining self-comparison and parallel inter-group comparison to systematically verify the impact of digital empowerment on the development of cultural tourism resources. First, 12 representative cultural tourism projects in Heilongjiang Province, encompassing diverse narrative themes such as ice and snow, revolutionary history, industry, and ethnic minorities, were selected. By comparing their operational panel data before and after digital transformation, the DEA model was used to

longitudinally assess the improvement in resource utilization efficiency. Second, to accurately measure the optimization effect on visitor experience, the “Harbin Central Street-Sofia Church Block,” which has undergone systematic digital transformation, was selected as the experimental group, while the “Harbin Daowai Historical and Cultural Block”—a comparable street block with similar historical architecture and baseline tourist traffic but without digital transformation—was selected as the control group. Visitor behavior trajectories, online reviews, and questionnaire data were collected simultaneously during the same time period, and the net effect of digital narrative was isolated through horizontal comparison. This design, through multi-source data fusion and rigorous comparison, ensures the reliability and validity of the research conclusions.

B. VERIFICATION OF THE IMPROVEMENT OF CULTURAL AND TOURISM RESOURCE UTILIZATION EFFICIENCY BASED ON DEA MODEL

This study selected 12 representative cultural tourism projects in Heilongjiang Province as decision-making units and constructed an input-oriented BCC model using Data Envelopment Analysis (DEA). Using operational panel data collected from actual project financial reports and visitor statistics before and after digital empowerment, the efficiency of input indicators was measured and compared. The input indicators included funding, human resources, facility maintenance, and digital infrastructure investment, which comprised both the initial capital expenditure for hardware procurement (Bluetooth beacons, Wi-Fi probes, environmental sensors) and system development, as well as the ongoing technical maintenance costs required to sustain the digital infrastructure mentioned in Section “VISITOR EXPERIENCE DATA PERCEPTION AND OPTIMIZATION STRATEGY GENERATION”. Output indicators included cultural narrative value rating and tourist arrivals. The experimental design focused on verifying the optimizing effect of digital technology on resource allocation efficiency. The comparison results are shown in Figure 1.

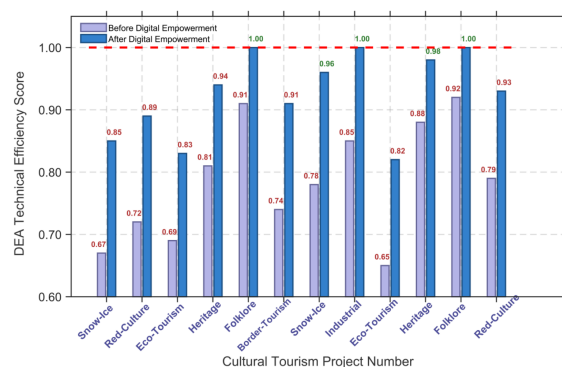


FIGURE 1. Evaluation of the efficiency of cultural and tourism resource utilization based on the DEA model

This experiment used the DEA model to verify the

significant improvement in the utilization efficiency of Heilongjiang’s cultural and tourism resources through digital empowerment. The results showed that the average comprehensive technical efficiency of 12 representative projects increased from 0.784 before empowerment to 0.926 after empowerment, an improvement of 18.7%; the number of DEA-effective projects also increased from zero to three. By explicitly incorporating both the capital expenditure and ongoing operational costs of digital infrastructure into the input side, the analysis ensures that efficiency gains are not overestimated due to omitted costs. Combined with authentic operational data, this provides a more complete and objective assessment of digital empowerment’s true impact.

C. VERIFICATION OF TOURIST EXPERIENCE OPTIMIZATION EFFECTS BASED ON MULTI-SOURCE DATA

This study selected a scenic area in Heilongjiang Province that had undergone digital transformation as the experimental group, and another similar scenic area the same city that had not undergone transformation as the control group. Using a multi-source data synchronous acquisition method, sensors were used to record tourists’ spatiotemporal trajectories, social media comment text was captured, and structured feedback was obtained through on-site questionnaires. Independent samples t-tests and association rule mining techniques were employed to compare and analyze the differences between the two groups of tourists in key indicators such as narrative node visitation rate and emotional feedback. The comparison results are shown in Table 2.

TABLE 2. Evaluation of Tourist Experience Optimization Effect Based on Multi-Source Data

Evaluation Metric	Experimental Group (Mean)	Control Group (Mean)	Improvement
Narrative Node Visit Rate	86.4%	61.2%	+25.2%
Average Visit Duration (minutes)	142.6	98.3	+45.1%
Positive Emotion Rate	78.9%	52.4%	+26.5%
Narrative Keyword Mention Frequency (times/person)	5.2	2.1	+147.6%
Heritage-Specific Sentiment Score (0–10)	8.3	4.7	+76.6%
Weaving Craftsmanship Appreciation Rate	72.4%	31.8%	+127.7%

The experimental results show that digital narrative transformation significantly optimized the visitor experience. The experimental group significantly outperformed the control group in terms of narrative node visit rate (86.4%), average visit duration (142.6 minutes), and emotional positivity rate (78.9%), with increases of 25.2%, 45.1%, and 26.5%, respectively. Visitors’ perception of the cultural narrative was significantly enhanced, with a 147.6% increase in the frequency of proactive mentions of narrative keywords. More importantly, fine-grained sentiment analysis revealed that digital interventions specifically deepened tourists’ engagement with the heritage narrative: the heritage-specific sentiment score reached 8.3 in the experimental group

versus 4.7 in the control group, and weaving craftsmanship appreciation rate increased by 127.7%. The data indicate that digital transformation based on multi-source data perception effectively improved visitors’ narrative immersion and experience satisfaction, with particularly strong effects on heritage-specific cultural perceptions beyond general satisfaction measures.

VII. CONCLUSION

This study demonstrates that digital empowerment can systematically enhance the efficiency of cultural narrative transformation and tourist experiences by integrating the historical value of Heilongjiang’s heritage into modern tourism development. This digital framework elevates the cultural resonance of traditional weaving techniques and industrial spinning sites, ensuring systematic conversion of craftsmanship into high-value immersive tourism assets. Based on establishing the cultural narrative value evaluation system and DEA model analysis, the efficiency of resource utilization was increased on average by 18.7%. The experience value evaluation based on multi-source behavioral data shows that the visit rate of tourist narrative nodes and the positive emotional rate increased by 25.2% and 26.5%, respectively. However, the sample of this study is limited to typical projects, and the generalization of research conclusions still needs further verification in the future, and the long-term tracking data are insufficient. Future research can expand to diverse cultural tourism scenarios across the province, integrating real-time dynamic data and artificial intelligence to construct an adaptive digital development model for traditional heritage and broader cultural narratives. This framework will facilitate the precise governance and continuous innovation of culture-tourism integration by digitally preserving weaving craftsmanship and industrial spinning history within an evolving, data-driven tourism ecosystem.

AUTHOR CONTRIBUTIONS

Zibo Pei designed, collected and analyzed the data, and drafted the manuscript. Zibo Pei conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Zibo Pei participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

The author declares no conflict of interest.

FUNDING

This research was supported by Heilongjiang Province Art and Science Planning Project ‘Research on the Development and Utilization of Heilongjiang Cultural and Tourism

Resources Based on the Evaluation of Cultural Narrative Value' (2025D039).

ACKNOWLEDGEMENTS

Not applicable.

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