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The Study of Poetical Style Attribution and Classification of Poetic Subgenres in the Tang and Song Poetry

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Abstract: ***The literary styles of Tang and Song poetry exhibit noticeable differences, at times directly denoting two distinct categories of poetic styles. However, sometimes the poetic style of Tang Dynasty poets may be more akin to Song poetry, and the poetic style of Song Dynasty poets may lean closer to that of the Tang Dynasty. This study employs quantitative analysis and establishes mathematical models to investigate these differences. Methods: Firstly, this paper employs a logistic regression model based on the simulated annealing algorithm to classify the style of poets and determine their style affiliation. Secondly, using the k-means clustering model, Tang and Song poetic styles are further refined into subcategories. Finally, scores are computed using the TOPSIS model modified by the entropy weight method to select the most representative poems and poets within each style. Conclusions: 1) The model identifies the style affiliation of Pei Che and Liu Yizhi as Song poetry style and Tang poetry style, respectively, with an accuracy rate of 83.3%. 2) The Tang poetic style is divided into three categories, and the Song poetic style is divided into five categories, with the first subcategory of Tang poetry including poems like "Passing Jin Yang Palace" and "Spring Platform Views." 3) The most representative poems include "Sending Xue Shaoqing to Qingyang" and "Introducing the Ballad for the Feast."***

Keywords: Tang and Song Poetry Styles; Logistic Regression Model; k-Means Clustering Model; Simulated Annealing Algorithm; TOPSIS with Entropy Weight Adjustment.

1. INTRODUCTION

He literary styles of Tang and Song poetry exhibit notable differences. Authors such as Qian Zhongshu, Yan Yiqing, and historian Miao Yue have all discussed the distinctions between Tang and Song poetry in their works. These distinctions are not limited to the time periods but also encompass entirely different literary styles. Fang Minjiang et al. [1] employed a logistic regression model for factor analysis in order to better predict student performance, utilizing penalty functions. Rigon Tommaso et al. [2] addressed the issue of the divergence of the maximum likelihood estimation in logistic regression models by considering conjugate prior penalties. Eshari Fatemeh et al. [3] proposed a new machine learning method to predict Protein Aggregation Propensity (PAP), a critical factor in amyloid-like fiber formation, based on logistic regression (LR). Zihao Deng et al. [4] first introduced a vertical federated non-learning method based on the logistic regression model. Soh Chin Gi et al. [5] used sparse fusion group lasso logistic regression (SFGL-LR) in combination with FTIR spectroscopy data to differentiate Greek and non-Greek organic olive oils. Li Jingqi et al. [6] employed an improved KMeans clustering method for regional division based on the geographical location and load situation of a distribution network area. Liang Ping et al. [7] proposed a feature extraction method based on the KMeans algorithm using text features from an English translation corpus. Gao Xu et al. [8] introduced an improved algorithm that combines KMeans with DBSCAN. Du Wensheng et al. [9] presented an end-to-end method based on an improved YOLOV5s and KMeans algorithm for detecting small spikes that need to be removed from grape inflorescences in a complex growth environment. He Junzeng et al. [10] proposed a rotor bearing system interval model verification method based on KMeans and Bayesian approach. Chen Cheng et al. [11] integrated entropy-based sequential sampling with Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) to determine new sampling points sequentially for HF and LF simulation. Jin Guangying [12] combined FMEA, Decision-Execution and Evaluation Laboratory Analysis (DEELA) methods with TOPSIS to analyze the uncertainty in the selection of virtual team members. Zhao Mengdie [13] used a Pythagorean trapezoidal fuzzy TOPSIS model to evaluate the water cycle health status of nine provinces. Kanwal Salma et al. [14] analyzed some molecular drug structures using multiple-criteria decision-making techniques, including TOPSIS and SAW. De Lima Silva Diogo Ferreira et al. [15] proposed a multi-criteria ordered classification TOPSIS method based on decision instances.

2. METHODS

2.1 Combining Logistic Regression Model with Simulated Annealing Algorithm

2.1.1 Selection of Indicators

To accurately classify a poet's style based on all their works, it is necessary to subdivide them into quantifiable indicators. Based on the collected data, the following definitions are provided for indicators with strong relevance to style classification.

Definition 1: Xk(1) represents the number of poems written by the k-th poet. Xk(2) represents the number of poems written by the k-th poet classified as Tang-style poems. Xk(3) represents the number of characters in the titles of the k-th poet's poems. Xk(4) represents the number of high-frequency characters in the k-th poet's poems, which reflect the Tang-style. Xk(5) represents the number of high-frequency characters in the k-th poet's poems that reflect the Song-style.

1) Proportion of Tang-style Poems

The formula for calculating the proportion of Tang-style poems in the poems written by the k-th poet is as follows:

$$PTP_k = \frac{X_k^{(2)}}{X_k^{(1)}} \tag{1}$$

This indicator describes the proportion of poems in the poet's works that belong to the Tang-style, reflecting the poet's style bias to some extent.

2) Proportion of Song-style Poems

The formula for calculating the proportion of Song-style poems in the poems written by the k-th poet is as follows:

$$PSP_k = \frac{X_k^{(1)} - X_k^{(2)}}{X_k^{(1)}} \tag{2}$$

This indicator describes the proportion of poems in the poet's works that belong to the Song-style, reflecting the poet's style bias to some extent.

3) Proportion of Title Characters

The formula for calculating the proportion of characters in the titles of the poems written by the k-th poet relative to the total number of characters in Tang-style and Song-style titles is as follows:

$$PTW_k = \frac{X_k^{(3)}}{N_1} \tag{3}$$

Where N1 is the total number of characters in Tang-style and Song-style titles. This indicator reflects the extent to which the titles of the poet's works are biased towards Tang-style or Song-style, thus having a strong correlation with style classification.

4) Proportion of High-Frequency Tang-style Characters

The formula for calculating the proportion of high-frequency characters that reflect the Tang-style in the poems written by the k-th poet is as follows:

$$PHT_k = \frac{X_k^{(4)}}{N_2} \tag{4}$$

Where N2 = 10 represents the number of selected high-frequency characters that reflect the Tang-style. Since high-frequency characters that reflect the Tang-style have been selected, this indicator describes the degree to which the poet's works are biased towards the Tang-style, and it has a strong correlation with style classification.

5) Proportion of High-Frequency Song-style Characters

The formula for calculating the proportion of high-frequency characters that reflect the Song-style in the poems written by the k-th poet is as follows:

$$PHS_k = \frac{X_k^{(5)}}{N_2} \tag{5}$$

Where N2 = 10 represents the number of selected high-frequency characters that reflect the Song-style. Since high-frequency characters that reflect the Song-style have been selected, this indicator describes the degree to which the poet's works are biased towards the Song-style, and it has a strong correlation with style classification.

2.1.2 Construction of Training and Testing Sets

Sixty-four poets from each of the two known styles are selected, and the corresponding data for their indicators are collected to create the training set. Among these, Du Fu, Han Yu, Bai Juyi, and Meng Jiao are considered representatives of the Song-style, while Zhang Lei, Jiang Kui, Xi Zhou, Bao Xian, Wen Zhao, Xing Zhao, Jian Chang, Wei Feng, Yu Zhao, Huai Gu, Hui Chong, Xu Zhao, Xu Ji, Weng Juan, and Zhao Shi Xiu are considered representatives of the Tang-style, and their indicator data are used for the validation set.

2.1.3 Model Steps

Let Xi represent the selected 5 indicators and their corresponding data, i = 1, 2, ..., 5.

The basic form of the logistic regression model is:

$$y = \frac{1}{1+e^{-(\omega^T x+b)}} \tag{6}$$

The probability description of logistic regression is:

$$p(y=0 \mid x) = \frac{1}{1+e^{(\omega^T x+b)}} \tag{7}$$

$$p(y=1 \mid x) = \frac{e^{(\omega^T x+b)}}{1+e^{(\omega^T x+b)}} \tag{8}$$

The parameters are estimated using maximum likelihood estimation, and the maximum "log-likelihood" of logistic regression is given by:

$$l(\omega,b)=\sum_{i=1}^{m}\ln p(y_i\mid x_i;\omega,b) \tag{9}$$

This means that it is best if the probability of each object belonging to the true class is as high as possible. In this paper, the simulated annealing algorithm is used to achieve this goal. The steps of the simulated annealing algorithm are as follows:

Set the maximum temperature Tmax, minimum temperature Tmin, and select an initial solution x. Here, Tmax = 100+273, Tmin = 273, both in Kelvin.

1) Inner Loop

At the current temperature T, randomly find a new solution y in the neighborhood of the initial solution x. According to the Metropolis criterion, determine whether to accept the new solution y and repeat until the inner loop conditions are met. Here, T is in Kelvin. The Metropolis criterion is explained as follows:

Given the solutions xi and xj with corresponding function values f(xi) and f(xj), if f(xi) > f(xj), then the current solution is set to xj. If f(xj) > f(xi), calculate r as follows:

$$r=\frac{f(x_i)-f(x_j)}{e^{KB\times T}} \tag{10}$$

Where KB is the Boltzmann constant, i.e., KB = 1.380649 × $10^{(-23)}$. Generate a random number ξ in the range [0, 1], and if it is less than r, then the current solution is set to xj, otherwise, it remains unchanged.

2) Outer Loop

If the current temperature reaches the outer loop temperature, stop the loop; otherwise, decrease the temperature and return to the inner loop step.

2.2 K-Means Algorithm

STEP 1: Determine the number of clusters, k.

STEP 2: Generate k random cluster centers.

$$C_i=(n_i^{\ m}) \tag{11}$$

Where i = 1, 2, ..., k, and m = 1, 2, ..., 5.

STEP 3: Determine the category, Ci, of each Tang poem based on distance.

$$dist(P_z,C_i)=\sqrt{\sum_{j=1}^{5}(X_z^{\ j}-n_i^{\ j})} \tag{12}$$

Where Pz=(Xzm), and Xzm represents the data corresponding to the m-th attribute of the z-th Tang poem, m = 1, 2, ..., 5.

STEP 4: Optimize the centers.

$$n_i^m = \frac{1}{\left|z_{c_i}\right|}\sum X_{z_{c_i}}^m \tag{13}$$

Where $\left|z_{c_i}\right|$ is the number of Tang poems in the i-th cluster, z_{c_i} is the Tang poems in the Ci cluster, i = 1, 2, ..., k, m = 1, 2, ..., 5.

STEP 5: Repeat STEP 3.

If there is no change in the classification, exit; otherwise, return to STEP 4.

Determine the value of k.

$$SSE = \frac{\sum_{i=1}^{k}\sum_{i=1}^{n_k} dist(c_i, p_j^{c_i})}{\sum_{i=1}^{k} n_i^m} \tag{14}$$

Where nim is the m-th feature of cluster Ci center, i = 1, 2, ..., k, m = 1, 2, ..., 5. Input values of k from 1 to 15 into the k-means algorithm to calculate SSE, determine the value of k based on the change in SSE, and then substitute the determined k value back into STEP 1 to continue the subsequent steps and obtain the clustering result.

2.3 TOPSIS Model with Entropy-Weighted Correction

STEP 1: Normalize the data.

For the analysis of Tang and Song style clustering, since there is a cluster center in each subcategory, select the poems with the most representative indicators in each subcategory to be as close as possible to the cluster center. This implies that the selected indicators are all central-type indicators, and they need to be transformed into maximum-type indicators.

$$X'_{ij} = \begin{cases} 1 - \dfrac{X_{ij} - a}{\max\{X_{ij}\} - \min\{X_{ij}\}}, X_{ij} > a \\ 1 - \dfrac{a - X_{ij}}{\max\{X_{ij}\} - \min\{X_{ij}\}}, X_{ij} < a \end{cases} \tag{15}$$

Where Xij is the data corresponding to the j-th indicator of the i-th object, is the data after normalization of the j-th indicator of the i-th object.

STEP 2: Standardize the data.

Use the following formula to standardize the data.

$$Z_{ij} = \frac{X'_{ij} - \min\{X'_{ij}\}}{\max\{X'_{ij}\} - \min\{X'_{ij}\}} \tag{16}$$

Where Zij represents the data corresponding to the j-th indicator of the i-th object after standardization.

STEP 3: Calculate the probability matrix.

$$P_{ij} = \frac{Z_{ij}}{\sum_{i=1}^{n} Z_{ij}} \tag{17}$$

Where Pij represents the probability corresponding to the j-th indicator of the i-th object.

STEP 4: Calculate information entropy and information utility value.

$$d_j = 1 + \ln n \sum_{i=1}^{n} [P_{ij} \ln P_{ij}] \tag{18}$$

Where dj represents the information utility value of the j-th indicator.

STEP 5: Calculate weights.

$$W_j = \frac{d_j}{\sum_{j=1}^{n} d_j} \tag{19}$$

Where Wj represents the weight corresponding to the j-th indicator.

STEP 6: Determine positive and negative ideal solutions.

$$\begin{cases} C_j^+ = \max\{Z_{ij}\} \\ C_j^- = \min\{Z_{ij}\} \end{cases} \tag{20}$$

Where Ci+ represents the positive ideal solution for the j-th indicator, Ci− represents the negative ideal solution for the j-th indicator.

STEP 7: Calculate the distance between each object and the positive and negative ideal solutions.

$$\begin{cases} D_i^+ = \sqrt{\sum_{i=1}^{n} (Z_{ij} - C_j^+)^2} \\ D_i^- = \sqrt{\sum_{i=1}^{n} (Z_{ij} - C_j^-)^2} \end{cases} \tag{21}$$

Where Di+ represents the distance of the i-th object from the positive ideal solution, Di− represents the distance of the i-th object from the negative ideal solution.

STEP 8: Calculate the scores.

$$f_i = \frac{D_i^-}{D_i^+ + D_i^-} \tag{22}$$

Where fi represents the score of the i-th object.

3. RESULTS AND ANALYSIS

3.1 Combining Logistic Regression Model with Simulated Annealing Algorithm

Validation dataset data was used in the logistic regression model to obtain style classification results for various poets in the validation set. These results were compared with the known styles to determine the model's accuracy. Some of the comparison results are shown in Table 1.

Table 1: Comparison of Some Poets' Results in the Validation Set

Poet	Predicted Style	Known Style	Poet	Predicted Style	Known Style
Du Fu	1	1	Jian Chang	0	0
Han Yu	1	1	Wei Feng	0	0
Bai Juyi	1	1	Zhang Feng	0	1
Meng Jiao	1	1	Jiang Kui	0	0
Wen Zhao	0	0	Xi Zhuo	0	0
Xing Zhao	0	0	Bao Xian	0	0

Here, 0 represents Tang style, and 1 represents Song style. Based on all the comparison results in the validation set, the model's accuracy can be calculated as 83.3%. This indicates that the model's predictions are reasonably accurate and align with the actual styles of the poets, making it suitable for determining poets' styles in the subsequent test set. Given the model's high accuracy, it demonstrates strong effectiveness and can be used for classifying poets' styles in the test set.

Using the established model, the test dataset was input into the model to obtain the style classifications for various poets in the test set. Some results for poets in the test set are shown in Table 2.

Table 2: Style Classification for Some Poets in the Test Set

Poet	Predicted Style	Poet	Predicted Style	Poet	Predicted Style	Poet	Predicted Style
Guan Qisun	0	Zhang Yansheng	1	Liu Yizhi	0	Jiang Jing	0
Yuwen Zhishao	0	Zhang Jianfeng	1	Yan Ye	0	Du Chang	0

3.2 k-Means Algorithm

3.2.1 Tang Poetry Clustering Results

Different values of k ranging from 1 to 15 were applied to the k-means algorithm to calculate the Sum of Squared Errors (SSE) for Tang poetry clustering, as shown in Figure 1.

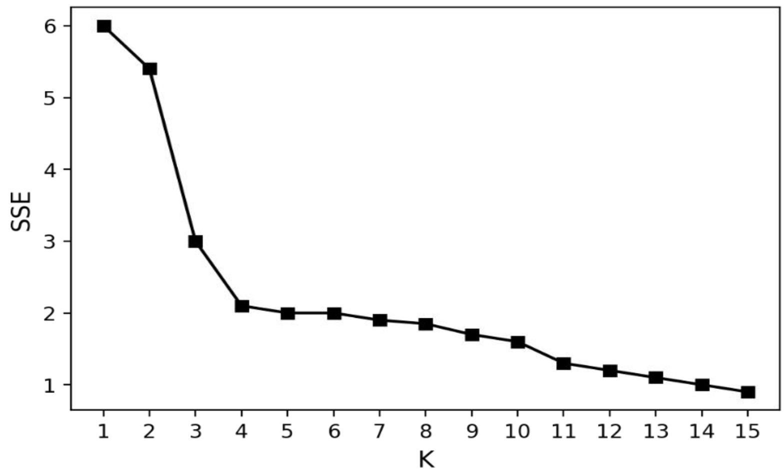

Figure 1: SSE vs. k for Tang Poetry

From Figure 1, it can be observed that when k is less than 3, SSE decreases significantly, while when k is greater than 3, SSE decreases slowly. Therefore, it is considered that the cluster structure is stable when k is set to 3.

With k=3, the model was used for clustering, and some of the clustering results are presented in Table 3.

Table 3: Partial Tang Poetry Clustering Results

Cluster	Poem	Cluster	Poem	Cluster	Poem
1	Holding the covenant, the three sides are calm	2	Passing by the old residence, first of two	3	Imperial Capital Poem, the tenth of ten
1	Singing of Sima Biao's continuation of the Han Annals	2	Returning to Shaan, expressing one's feelings	3	Drinking while riding to the Great Wall's caves
1	The Crown Prince receives a consort, Princess Taiping surrenders	2	In Beiping it is composed		

3.2.2 Song Poetry Clustering Results

Similar to Tang poetry, different values of k ranging from 1 to 15 were applied to the k-means algorithm for SSE calculation for Song poetry clustering, as shown in Figure 2.

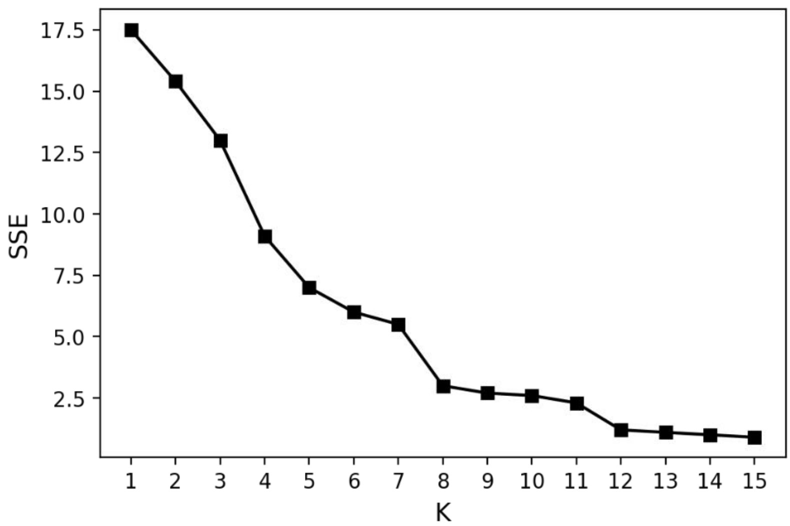

Figure 2: SSE vs. k for Song Poetry

From Figure 2, it can be observed that when k is less than 5, SSE decreases significantly, while when k is greater than 5, SSE decreases slowly. Therefore, it is considered that the cluster structure is stable when k is set to 5.

With k=5, the model was used for clustering, and some of the clustering results are presented in Table 4.

Table 4: Partial Song Poetry Clustering Results

Cluster	Poem	Cluster	Poem	Cluster	Poem	Cluster	Poem
1	Clouds	2	Singing of History	3	Harmony and Wisdom, a Song of Merit	4	Ascending the tower by the Jiang River in Rongzhou, leisurely gazing
1	Four Miscellaneous Poems, the Fourth	2	In the Dragon's Temple, farmers pay homage to the gods	3	Instructing the nephews and nieces with eight hundred characters	4	Snow

3.3 TOPSIS Model Modified by Entropy Weighting

3.3.1 Tang Poetry Evaluation Results

Partial Tang poetry evaluation scores are presented in Table 5.

Table 5: Partial Tang Poetry Scores

Cluster	Poem	Score	Cluster	Poem	Score
1	Flute and Lyre Poetry - "Mountain Moon"	0.8491	2	Temple Hymn Poetry - "Sealing the Tai Mountain Ode, Melodies of Yonghe"	0.9933
1	Lyre and Reed Poetry - "Toasting"	0.8227	3	Early Ascent to the Taihang Mountains and Expressing Ambitions	0.9835
1	Lyre and Reed Poetry - "Battle at the Southern City"	0.7725	3	Flute and Lyre Poetry - "Yin at the Head of Long Mountain"	0.9297
2	Tang Ming Hall Ode - "Imperial Heir's Comings and Goings, Ascending and Descending"	0.9933			

Based on the scores of each poem in each cluster, higher scores indicate greater representativeness for that cluster. Therefore, the most representative poems for each cluster in Tang poetry are: Flute and Lyre Poetry - "Mountain Moon", Lyre and Reed Poetry - "Toasting", Lyre and Reed Poetry - "Battle at the Southern City", Tang Ming Hall Ode - "Imperial Heir's Comings and Goings, Ascending and Descending", Temple Hymn Poetry - "Sealing the Tai Mountain Ode, Melodies of Yonghe", Early Ascent to the Taihang Mountains and Expressing Ambitions, Flute and Lyre Poetry - "Yin at the Head of Long Mountain".

3.3.2 Song Poetry Evaluation Results

Partial Song poetry evaluation scores are presented in Table 6.

Table 6: Partial Song Poetry Scores

Cluster	Poem	Score	Cluster	Poem	Score
1	Sending Xue Shaoqing to Qingyang	0.9208	3	In Harmony with the Grand Palace Prefect, Nostalgia, and Sending Forty Rhymes	0.6505
1	Sending High Official Gao to Jing County	0.8775	4	The sixth of the Ten Songs of Willow Branches	0.9936
2	In Rhyme with Lord Ling, a Poem About Roses	0.8415	4	Sent with a letter to Zhong Lang, and subsequently sent to the courtesan in the capital, Yue Bin	0.9913
2	In Rhyme, Offering a Poem on the Thousand Leaves of Roses	0.7384			

The most representative poems of various sub-genres of Song poetry include: "Sending Xue Shaoqing to Qingyang, " "Sending Gao Qiju to Jing County, " in the style of rhyme and in response to Lord Linggong's Rose Poem, "In Rhyme and Tribute to the Thousand Leaves of Roses, " "In Tribute to Gong Fu Xianggong's Nostalgia with Forty Rhymes, " and "A Song of Capital Wisdom and Prosperity." Also, "Four Poems on Willow Branches" with the third one, and "Twelve Poems on Willow Branches" with the sixth one, and so on.

4. CONCLUSION

This article first combines the simulated annealing algorithm, which has high search efficiency and can improve the model's solving speed. Secondly, it uses a logistic regression model to determine the style attribution of poets and validates the model. The test results show high accuracy and strong persuasiveness. Then, a k-means clustering model is applied to cluster Tang and Song poems, with optimization of the cluster centers, resulting in better clustering outcomes and improved performance. Finally, the article selects various indicators from the features of poems and establishes a TOPSIS model corrected by the entropy weight method to select several of the most representative poems in each style subclass.

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