



Research on Zoning Identification and Governance Strategies for Ecological Restoration of Transmission Lines Driven by Multi-source Factors

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SUMMARY: *To address the complex ecological disturbances along transmission lines and that the restoration areas are not clearly identified, a regional identification and management system for multiple factors has been put forward in this study. A graph-structured input system with the five types of categories has been built: topography, hydrology, soil, land use and human activity. Fuzzy C-means and spectral clustering are combined for partition modelling, and a strategy template response matching mechanism is also employed. A rolling optimisation module is added to support block-level management of the deployment pathway. A typical ecological pattern in Jiangxi Province is selected as the experimental area. Approximately 97.4 kilometres of a strip-shaped simulated corridor is taken out independently as the modelling area in the regional background data framework. Thus, 236 grid units and 117 disturbance samples were created for the comparative experiments. According to the above experimental results, the new way of zoning recognition outperforms that of the previous methods in terms of zoning recognition accuracy (94.6%), policy hit rate (91.4%), and boundary coherence (85.3%); it is also highly reliable and feasible for use in engineering applications. This paper puts forward a multi-factor graph model to improve the accuracy of ecological restoration zone identification for transmission lines and achieve closed-loop optimisation of disturbance identification and strategy scheduling.*

KEYWORDS: *Graph model; Clustering; Disturbance; Optimisation*

1 Introduction

Ecological restoration of the transmission line area will be part of the ecological governance for the construction of power grids. A multi-source factor-driven identification mechanism is now used instead of the former experience-based zoning to determine ecological risks and restoration capabilities. As the area of the expanded transmission lines in different areas increases, so too will the types of ecological damage; therefore, the corresponding requirements for restoration are also growing. Currently, the zoning standards are inconsistent; factor data and processing methods are lacking, thus reducing the accuracy of restoration implementation. The ecological features are not the same in the transmission corridors; thus, a single index cannot be used to assess regional vulnerability. At the same time, a large number of diverse datasets and complex correlations among them are also harder to identify for zoning. The above problems indicate that a restoration zoning system should be built on multiple ecological factors

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to enhance the scientific basis and practical operation of governance.

The four ecological types of the areas along the transmission lines are: forested areas, farmland, water-conservation zones and exposed surfaces. Most of the construction information is stored in the engineering management platform, and the ecological monitoring system only covers key protected and highly sensitive areas; thus, continuous data for the general section is lacking. Large spatial scale, uneven ground and inconsistent construction practices result in scattered degradation patterns, and hidden ecological deterioration is thus difficult to observe with a single monitoring method. Low-frequency manual observations, scattered ecological data sources and changes in weather have all reduced the accuracy of degradation detection. Over time, the removal of obstacles, equipment maintenance and corridor maintenance will be more frequent; therefore, the repair demand will rise. Given the above circumstances, the results of experience-based restoration assessments are unreliable; therefore, a system of multi-source factor-driven repair demand identification is needed.

1.1 Problems and limitations existing in the current repair management

The ecological restoration system of the transmission line is still in a manual-inspection mode, without a standardized data-driven framework for zoning and governance. Although remote sensing and UAV data have improved the acquisition of surface information, there are still problems with inconsistent granularity, weak timeliness and poor integration; thus, the restoration zone is not systematic and timely intervention is difficult.

Key Technical Constraints Still Exist. Current zoning is based on a single index and neglects multiple factors in the environment, thus failing to classify sensitive areas properly. Ecological data are distributed in various departments, vary in scope and format, and thus cannot be integrated across scales to connect local actions with regional ecological features. The present restoration model is a fixed-parameter type that does not have a dynamic-update function and is thus not suitable for complex environments. Governance technology is frequently used uniformly and fails to consider the different conditions of various plants and soils. Restoration evaluation does not have a unified quantitative measure and is not continuously updated.

The above problems are due to a lack of resource utilisation and unstable recovery. Therefore, a multi-source factor-driven degradation identification mechanism that integrates machine learning and graph modelling is needed to extract factor correlations and define restoration areas more precisely. A multi-source zoning method and a heterogeneous block-level governance strategy framework are introduced in this study, and sensitivity indicators and rolling optimisation are employed to improve the accuracy and stability of ecological restoration for transmission lines.

2 Relevant work

With the progress of ecological civilisation, transmission lines are facing more and more problems of delayed disturbance identification and inappropriate restoration strategies in complex ecological regions. Current zoning practice is still based on manual inspection and empirical judgment; it has low accuracy, limited coverage and a slow response speed, and thus fails to meet the intelligent governance demands for various landforms and disturbance types. In order to provide a basis for scientific and data-driven restoration planning, some researchers have been conducting studies on the selection of factors, data fusion, model construction and strategy adjustment to develop various zoning and governance mechanisms.

Traditional GIS- and experience-based restoration methods are not suitable for the spatiotemporal variations in ecological damage. Recently, remote sensing indicators, NDVI and

other hydrological factors and habitat integrity indices have been introduced to the model of restoration factors. Yin and others (2025) determined the sensitive corridor area based on landscape connectivity [1]. Che and others (2025) have developed a soil-based vegetation response model to improve the method for vertical disturbance detection [2]. Sun et al. (2024) combined construction-period remote sensing with dynamic risk factors to support the construction of ecological risk perception [3]. Parihar et al. (2017) built a "factor-scene-intervention" model and a disturbance ranking system for priority restoration [4], but these methods are still based on relatively static information.

At present, machine learning and graph algorithms are being used in clustering and detection models to deal with all sorts of reasons and class confusion. Zhang and others (2023) put forward a clustering framework for ecological security patterns and landscape fragmentation [6]. Li and Lin (2019) used NDVI and MODIS time series to model disturbance trends after the line operation [7]. Rezaian (2016) considered high-weight disturbances in terms of human activity density [8]. Ji et al. (2024) and Zhao et al. (2025) have presented YOLO-based detection models for construction intrusion and high-frequency environmental factors to improve dynamic disturbance recognition [9, 10]. Most of the current models are single-task oriented and lack the mechanism of multi-factor collaborative expression; thus, they have shown poor generalisation in complex areas, such as the Hengduan Mountains and water conservation zones.

Adaptation of Strategy is also a problem. Jang and others (2025) built a species-environment suitability matrix for adaptive technical recommendation [12]. Li and others (2022) have used lithology, slope aspect and moisture in their work on slope management [13]. Mota and Lima (2024) used graph-based shortest path modelling to prioritise the restoration section [14]. Gao et al. (2025) proposed a sensitivity-based path matching method for cross-river sections [15], and Fan et al. (2025) integrated circuit theory and PLUS modelling to connect ecological pressure distribution with restoration paths [16].

To present the research methods, the relevant materials of the study will be presented in Table 1.

Table 1: Comparison of Research Methods for Ecological Restoration Zoning and Governance Paths of Transmission Lines

Document reference number	Methodological Types	Core algorithm /model	Data type	Technical Advantages	Principal limitations
[1]	Landscape ecological assessment	Connectivity Metrics Analysis	Remote sensing imagery + DEM terrain data	Supporting the identification of ecologically sensitive corridors, with a clearly defined structure	Difficult to detect minor disturbances
[3]	Risk Early Warning Modelling	Compound Factor Risk Function	Construction-phase telemetry + meteorological + measured interference factors	Suitable for dynamic tracking, with low deployment costs	Deployment is constrained by reliance on on-site monitoring data.
[9]	Visual Inspection Modelling	STAE-YOLO Network	Video stream + image structural features	Capable of real-time identification of high-risk devices, suitable for deployment at the front end of the identification process.	Training samples require annotation, cross-domain transfer is challenging.
[12]	Restore path matching	Environmental-Species Adaptability Mapping Matrix	Slope + Precipitation + Species Distribution Data	Enhance path governance stability and support rolling adjustments	Lacks resilience in regions with extreme topography
[14]	Network Optimisation Planning	Graph Theory Shortest Path Algorithm	Corridor node + clearance zone boundary data	Supporting optimal path design across the entire network segment	Difficult to embed within governance technology constraints
[16]	Modelling of Spatial Security Structures	Circuit Theory + PLUS Model	Land category data + Electric field structure flow model	An ecological pressure map can be constructed to identify strategic blockage points.	The algorithm is computationally intensive and requires comprehensive ecological flow field data to function effectively.

Based on the research above, it can be seen that the current related studies on the ecological restoration of transmission lines have made substantial progress in the following areas: identification of ecological factors, construction of zoning mechanisms, visual-assisted identification, and selection of governance paths. However, the following deficiencies still exist:

i. Most models are based on a single type of data or lack cross-modal collaboration mechanisms, so it is difficult to maintain the stability of feature expression after the fusion of multi-source heterogeneous data. Most of the partition algorithms are static structures without a real-time feedback loop, and therefore cannot respond to the reclassification requirements of the treatment area caused by disturbances and changes during the construction period. iii. Path matching is mostly based on manual rules and lacks a governance path adaptation mechanism driven by data. The connection between the identification results and the governance plan is weak; as a result, the plan for strengthening enforcement capacity and adjusting based on feedback has not been proposed.

Given the above, this paper aims to put forward a transmission line ecological restoration zoning identification and governance path system that integrates multi-source expression of factors, strategy adaptation mapping, and a rolling optimisation mechanism, constructing a four-stage technical system of "factor-driven - zoning clustering - strategy recommendation - closed-loop execution" to enhance the accuracy, timeliness and executability of ecological restoration intervention.

3 Method

3.1 Multi-source Factor-driven Repair Area Identification Strategy and Scheme Construction

3.1.1 Factor selection and weight integration Strategy

In the identification of ecological restoration zones based on multiple sources of information, the ecological attribute data from these various sources are in heterogeneous, non-linear, and spatio-temporally varying states, and therefore need to be uniformly modeled through normalisation and weighting processing. The five categories of ecological factors in this paper are topographic factors, surface cover factors, soil factors, climatic factors, and human disturbance factors; these are, respectively, obtained from DEM elevation models, land use remote sensing layers, soil organic matter samples, annual average climate grid data and construction trajectory records. To ensure that all factors are in the same spatial reference and can be normalised uniformly, an interval normalisation function is used for generalisation:

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (1)$$

X X_{min} X_{max} X_{norm} Among them, is the value of the original ecological factor, and respectively represent the minimum and maximum values of this factor in the sample set; is the normalized factor value. This normalisation function keeps the factors of different dimensions in the same range of numbers and is therefore suitable for the next weight aggregation and clustering model.

Given the different responses of factors to ecological degradation, a structure of factor weight distribution is built in this paper according to the entropy weight method. The Entropy Weight is as follows:

$$w_j = \frac{1 - e_j}{\sum_{j=1}^n (1 - e_j)} \quad (2)$$

e_j , j , w_j , n Among them, is the entropy value of the factor; is its corresponding weight; and represents the total number of all factors. Based on the above method for distributing weights, the contribution of factors is determined according to their variance, and the impact of factors with strong information dominance in the repair partition is enhanced.

In order to realise the alignment of features and weights for multiple sources of ecological factors, this paper puts forward a general recognition strategy process for factor collection, normalisation processing, weight calculation and policy feedback. This process is based on the structured integration of heterogeneous factors, supplemented by the index weighting method driven by information entropy, and through the closed-loop mechanism of governance path output and state feedback, it realizes the system linkage structure of repair partition identification and dynamic adaptation. The general structure is as follows: Figure 1.

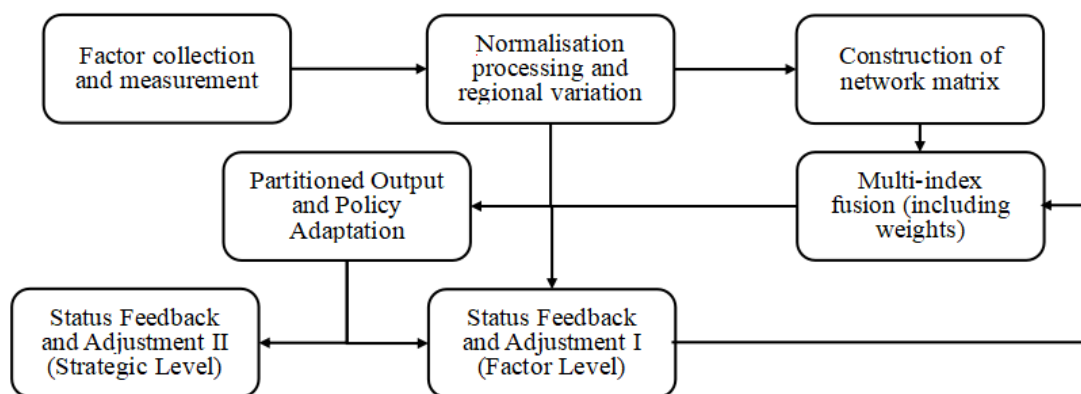


Figure 1: Structure Diagram of the Repair Area Identification Strategy Driven by Multi-source Factors

3.1.2 Process Design of Partition Identification Scheme

The four stages of the ecological restoration zoning identification scheme based on multi-source factor fusion proposed in this paper are as follows: data preprocessing, factor integration, regional zoning modelling and execution of governance strategy mapping. Build a multimodal factor matrix, use weight-driven and clustering feedback mechanisms to dynamically locate areas of ecological damage in transmission corridors, and revise governance plans.

i. Data Preprocessing Stage: Regularisation and Normalisation processing of the original multi-source ecological factors are mainly carried out at this stage. Sources of the factors include remote sensing images, topographic and geomorphic data, climate and hydrological monitoring values, human activity indices, etc. First, remove missing values and then fill in outliers. Then, all the indicators in each dimension are uniformly normalised by the normalization function to obtain a set of normalization factors. Subsequently, according to the grid zoning logic of the ecological plot, a spatial unit factor matrix has been built to ensure positional consistency and regional comparability of the factor expression. To improve the recognition ability of different regions in the environment, a sliding window method is used to perform local smoothing operations on adjacent areas and thus reduce the effect of a sudden change at the boundary on the model's clustering performance.

ii. Factor Fusion and Regional Structure Expression Stage: Based on the normalised factors and their weight parameters, the multi-dimensional ecological factors in each spatial cell are weighted and fused to calculate and generate an all-encompassing ecological disturbance index. All cell results are combined to form an interference index matrix, and a sensitivity expression layer over the study area is constructed. Next, based on the ecological attribute differences of

adjacent cells in space, a connectivity relationship map for the cells is constructed to obtain the regional adjacency map. As shown in the graph below, the extent of ecological damage in different ecological Areas is either the same or spatially correlated. A connection threshold is used to eliminate loosely connected edges, and areas that are significantly more uniform ecologically are kept to construct a candidate restoration partition structure with spatial constraints. The above partitioning structure provides a basis for the following classification clustering and governance path matching, as well as an intermediate expression result with good coherence and interpretability for the division of governance areas.

iii. Regional Zoning Modelling Stage: Based on the built regional structure, density-aware clustering algorithms are used to group ecological cells and identify three types of areas: disturbance zones, potential recovery zones, and stable ecological zones. The classification results are encoded as ecological sensitivity-level labels, and among them, the highly sensitive areas are considered the intervention objects with the highest restoration priority. To ensure the interpretability of the classification results, a label-correction mechanism based on neighbourhood consistency is used to eliminate local outlier misjudgment regions by the model. At this time, a confidence threshold mechanism will also be used to dynamically adjust the labels of the fuzzy regions at the boundaries of the cluster and enhance the stability and boundary-control capability of classification.

iv. Path Matching and Feedback Optimisation Stage: After finding the repair area, the system will use the attribute information of different areas to call the corresponding governance strategy library and select an appropriate repair technology path. Governance strategies include several governance technology templates, such as vegetation restoration, hydrological guidance and artificial intervention, and can automatically generate operation lists according to the regional ecological structure. Output the strategy path, and then compare the recognition results with the remote sensing dynamic layer in the construction period. If it is too high or too low, then the factor weights and division factors will be modified. A closed-loop process is employed to support the rolling update of governance paths, thus ensuring that identification results can be continuously optimised over time and improving the adaptability and execution efficiency of the ecological restoration zoning identification system.

The partition identification scheme creates a closed-loop system involving data structures, factor fusion and path adaptation, and is highly adaptable and scalable. The partitioning results can be used directly as the input for the following clustering modeling and strategy linkage modules to build the foundation of data and structure for a dynamically adjustable ecological restoration system.

Figure 2 shows the typical cross-section structure of transmission corridors and their ecological boundary zoning to better understand the spatial scope of the definition of ecological disturbance. At the centre of the corridor is a high-voltage transmission channel, and buffer zones 10-20 metres wide are set up on both sides. The type of vegetation in this area is subject to restoration intervention and management control, and thus is a key target area for zone identification and strategy deployment.

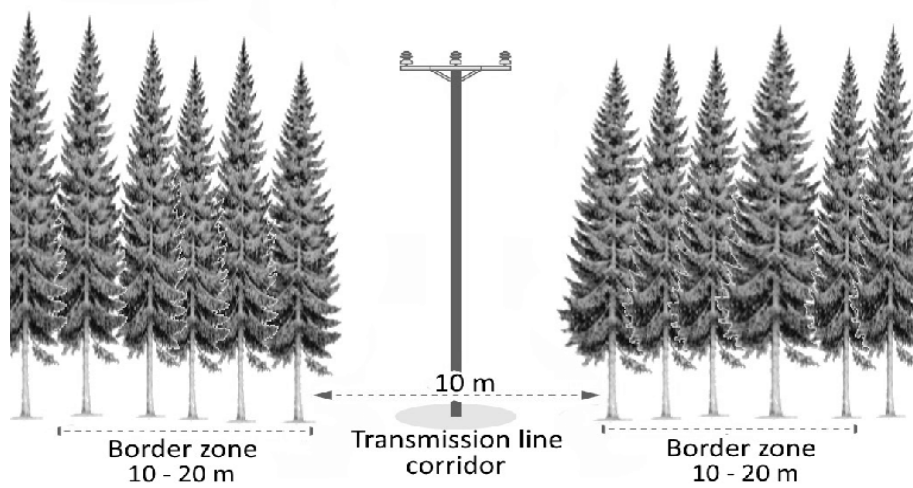


Figure 2: Schematic diagram of the structure of the transmission line corridor and the ecological disturbance boundary section

The shape of the transmission corridor in the figure is as follows: About 10 meters in the middle of the corridor is used for the tower base and conductor structure, and the widths of the boundary areas on both sides range from 10 to 20 meters and are often located in forest land or shrublands. The above structure diagram can help us understand how far away the lateral diffusion range and spatial coherence of ecological factors are in the process of identifying disturbance boundaries.

3.2 Multi-source Heterogeneous Data Fusion and Factor Evaluation Mechanism

3.2.1 Data Types and Index System Construction Methods

In order to identify multi-source factors and adapt repair strategies for the ecological interference zoning of transmission lines, the structure of the data needs to be known first, and then a uniform and scalable index system must be established. The data in this paper are as follows: topography, climate, hydrology, land use, vegetation cover, construction disturbance, and physical obstacles. The data sources are remote sensing images, unmanned aerial vehicle (UAV) aerial photography, ecological monitoring equipment, construction logs and historical planning layers. To ensure the uniformity of model input, dimension normalisation, format standardisation and attribute unification conversion need to be carried out for heterogeneous data. Plot is taken as the smallest unit of analysis, and a multi-dimensional factor matrix is constructed for each spatial unit. The components of the matrix are the ecological indices from various places. Identify the primary characteristics and a time-series control for a single-factor expression system of spatial mapping.

Construction of the indicator system aims to exclude irrelevant indicators and keep the essential ones. To avoid multicollinearity among the factors that will be used to calculate the fusion weights, an initial weight is given to each ecological indicator via the information entropy method. The expression for the weight is as follows:

$$w_i = -\frac{1}{\ln n} \sum_{j=1}^n p_{ij} \ln p_{ij} \quad (3)$$

w_i is the entropy weight of the factor, n is the total number of samples

for this factor, and is the normalized proportion of the factor in the sample. The above formula is used to find the level of information decentralisation for each ecological factor. A larger weight value means that it will be relatively more responsible for the partition of regional ecological characteristics.

Based on the calculated fusion weights, all factors need to be weighted and combined to form an all-encompassing ecological disturbance index for regional differentiation. The formula of the weighted combination is as follows:

$$S_k = \sum_{i=1}^m w_i \cdot x_{ik} \quad (4)$$

S_k Among them, is the overall interference score of the regional unit; is the total number of ecological factors included in the calculation; is the weight value assigned to each factor; and is the normalised value of the factor in that spatial unit. The above index will be used as the basic input for repairing the partition model.

A uniform data expression format and a weight fusion mechanism are used to provide stable and well-structured input features for the restoration area classification model, improve the comparability and adjustability of regional heterogeneous factors, and build a high-quality data foundation for the partition determination model and governance path matching mechanism.

3.2.2 Multi-source factor Normalization and collaborative Analysis method

Given that the physical sources, measurement units and spatio-temporal scales of various ecological factors in the identification of ecological restoration areas for transmission lines are quite different, unified normalisation processing needs to be carried out first to ensure that the results of collaborative analysis are comparable. Interval standardisation is used in this paper to map all the data of ecological factors linearly to the [0,1] range for subsequent clustering and sensitivity analysis. The normalisation computation is as follows:

$$x_{ik}^* = \frac{x_{ik} - x_i^{\min}}{x_i^{\max} - x_i^{\min}} \quad (5)$$

x_{ik}^* Among them, is the value of the normalized factor in the spatial unit; is the original value; and and are the minimum and maximum values of this factor across all units, respectively. Normalisation keeps the relative variation trend of each factor and removes the impact of different dimensions.

Normalised data are then employed in the C-means fuzzy clustering algorithm to identify different areas of ecological disturbance features. The method performs weighted optimisation of the distance between cluster centers and samples by minimising the objective function. The primary purposes of these are as follows:

$$J = \sum_{k=1}^n \sum_{i=1}^c u_{ik}^m \cdot \|x_k - z_i\|^2 \quad (6)$$

J Among them, is the loss function of fuzzy clustering; is the number of samples; is the number of clusters; is the sample vector; is the cluster center; is the membership degree of the sample belonging to the category; and is the fuzzy weighting index. The above function is used to check if the division of the current cluster matches the distribution

of actual samples. The lower bound of the range is 2; otherwise, a large distance will be introduced in the clusters. m

First, based on the current membership degrees in a given iteration, the positions of the cluster centers are updated. The update method of the cluster centres is as follows:

$$z_i = \frac{\sum_{k=1}^n u_{ik}^m \cdot x_k}{\sum_{k=1}^n u_{ik}^m} \quad (7)$$

Among them, z_i is the cluster centre vector, u_{ik} is the membership degree of the sample to this class, x_k is the sample vector, and m is the fuzzy factor. The new cluster centre will be positioned at the distribution centre of its member samples, and thus more representative of the samples.

Based on the new locations of the cluster centres, the membership degree values for each sample are then updated. The Method of Actual Calculation is as follows.

$$u_{ik} = \frac{1}{\sum_{j=1}^c \left(\frac{\|x_k - z_i\|}{\|x_k - z_j\|} \right)^{\frac{2}{m-1}}} \quad (8)$$

Among them, u_{ik} represents the membership degree of sample to the category, x_k and z_j are the clustering centers of each category, and m is the fuzzy factor. A formula is employed to quantify the degree of belonging to each class centre for a given sample, and the sum of all such degrees should equal 1.

Fuzzy partitioning is based on normalising data to enable samples to belong to multiple classes with different degrees of membership, thereby accommodating the partitioning characteristics of multi-factor coupling and blurred boundaries in the ecological zone of transmission lines. Dynamically adjust and modify membership degrees to identify the potential aggregation structures of ecological disturbance areas; enhance the accuracy and stability of zoning identification; and provide specific input support for the formulation of governance strategies.

3.3 Fix the partition determination model and the selection of clustering methods

Due to the complex spatial distribution of ecological factors and uneven interference weights, as well as the heterogeneity of terrain and environment during the ecological restoration of transmission lines, the traditional zoning method based on a single-index threshold is unable to accurately determine the governance boundary. To improve the connection and sensitivity of the partition recognition function, a clustering partition determination model based on graph structure modeling has been proposed in this paper. The four parts of the general plan are as follows: construction of the factor vector, construction of the adjacency graph, node embedding and regional clustering (see Figure 3).

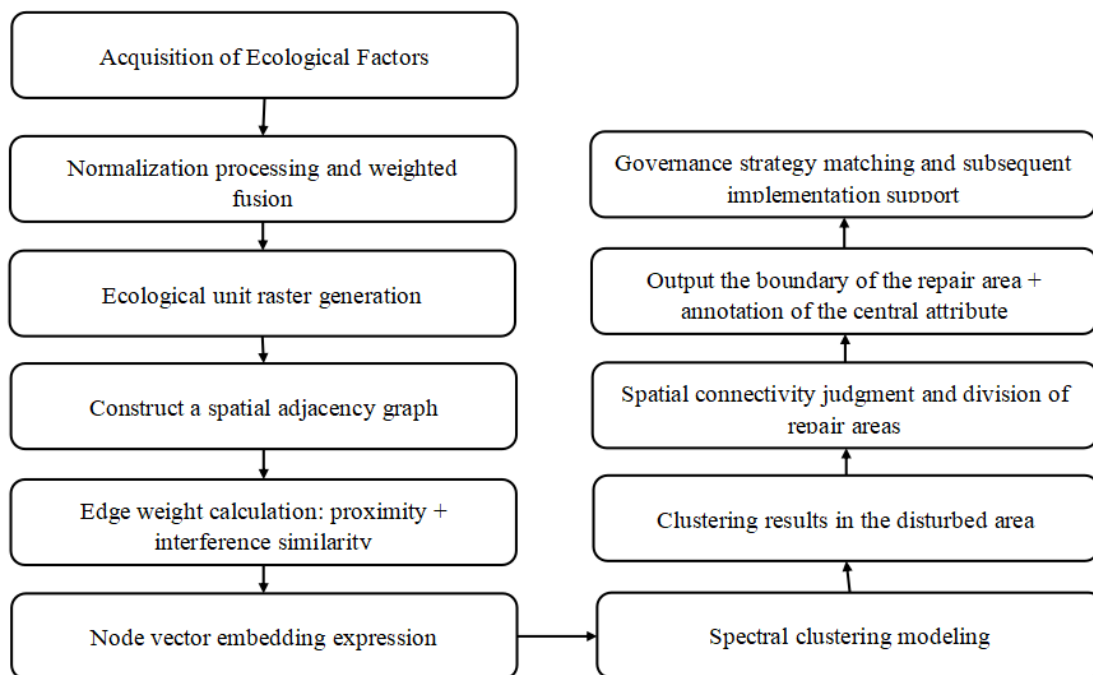


Figure 3: Flowchart for Repairing the Partition Determination Model

Weighted fusion is used to generate ecological feature vectors for all nodes, and these nodes correspond to raster data of ecological areas. Based on the spatial proximity and degree of interference, edge weights are determined to build a weighted adjacency graph for the graph structure. Apply spectral clustering to extract the structure-feature diagram presented in Figure 2. Feature decomposition is used to find the potential clusters in the figure, and no predefined categories are required. Adaptively adjust the Boundary Determination of the ecological disturbance area.

Nodes that are close in space and have similar disturbance characteristics will be grouped in the same area to form a governance unit with an organised structure and uniform attributes. Due to a lack of labels in the training stage, a pseudo-label method and self-supervised augmentation were introduced to guide the expression of embeddings towards cluster consistency and solve the problem of inaccurate judgment in the boundary fuzzy area.

The output results are in the form of layers; each layer shows the boundary and central attribute values of an ecological disturbance area, and thus provides a spatial basis for allocating governance resources and matching technologies. This plan can solve the problem of manual division errors, inconsistent attributes and subjective classification, show excellent recognition accuracy and practical engineering value, and have the generalisation ability to adapt to various complex situations in different areas.

3.4 Governance Strategy Path Formulation and Solution Adaptation Mechanism

3.4.1 Classification of Regional Attributes and Grading of ecological sensitivity

In the attempt to construct a comprehensive system of ecological restoration measures for the power line network, the region's specific ecological conditions will be classified and assessed for vulnerability to formulation first. Regional Features include topography, vegetation cover, hydrogeological conditions and the extent of ecological modification. Assess the ecological vulnerability of all areas using a general factor expression model. Assume that each regional

unit has attribute indicators, and the corresponding standardised weight vector is $w = (w_1, w_2, \dots, w_n)$. Then the regional ecological sensitivity score can be computed according to the above formula.

$$S_i = \sum_{j=1}^n w_j \cdot x_{ij} \quad (9)$$

Among them, S_i represents the sensitivity score of the regional unit; x_{ij} represents the normalised value of this area on the indicator; w_j represents the weight of the indicator. The above formulas are used to sum up the impacts of all factors in various areas and show the overall ecological response strength of that area.

To further support the classification of repair levels, a grading determination is made based on a sensitivity score of S_i , and a piecewise mapping function is constructed as follows:

$$G_i = \begin{cases} 1, & S_i \leq \theta_1 \\ 2, & \theta_1 < S_i \leq \theta_2 \\ 3, & S_i > \theta_2 \end{cases} \quad (10)$$

Among them, G_i is the sensitivity classification result of the region, and θ_1 and θ_2 are the empirically set sensitivity classification thresholds. The division of areas in terms of governance sensitivity includes low-sensitivity, medium-sensitivity and high-sensitivity, and therefore various countermeasures have been introduced.

3.4.2 The logic of the repair technology selection matches the governance path

There are many variations in the traits of the areas for ecological restoration. Given that the landforms and the types of disturbances and evolutionary risks in the various areas are different, different governance technologies and paths need to be selected. Therefore, a region-technology map construction mechanism needs to be built. Based on the matching degree between the regional attribute vector and the technology adaptation matrix, the repair adaptation index is determined by a weighted distance function to quantify how well a region matches a governance technology. It is shown as follows:

$$R_{ij} = 1 - \frac{\|A_i - T_j\|_2}{\max_k \|A_i - T_k\|_2} \quad (11)$$

Among them, A_i is the attribute feature vector of the region; T_j is the feature response vector of the type of repair technology; $\|A_i - T_j\|_2$ is the Euclidean distance, which quantifies the attribute difference between the two, and a larger value indicates a higher degree of match. This index helps select the most appropriate match among multiple technical options for precise repair technology pushing.

A corresponding degree matrix is obtained, and then, according to this, a governance path matrix is constructed to list the sequence of governance actions for each area. Considering the dependence relationship among path nodes and cost constraints, let \mathbf{x} be the path cost vector, and select the path with the smallest cost through the objective function:

$$P_i^* = \arg \min_{P_i} \sum_{k=1}^l C_i(k) \cdot \delta_k \quad (12)$$

P_i^* Among them, represent the optimal governance path for the area, indicate the cost coefficient of the path node, and are the Boolean variables to determine whether to execute this node. This function will automatically select a path sequence that meets the cost constraints and is feasible to implement; thus, it will satisfy the attributes of the strategy and significantly improve the deployment efficiency of the governance system.

3.4.3 Linkage Mechanism of Governance Strategies for Different zones

Ecological restoration work on the power transmission network in different areas shows considerable differences in terms of the sensitivity of nature, types of environmental problems and technical factors, and therefore, the governance strategies adopted at these locations are not uniform. Strengthen coordination and responsiveness at all links of the restoration system to build a link-regulation mechanism for governance strategies and foster dynamic synergy among regional governance paths. A linkage function based on policy tensors is constructed in this paper to model the interaction relationships among various repair zones in terms of time, space and resources, and it is shown as follows:

$$L_{ij} = \lambda_1 \cdot S_{ij} + \lambda_2 \cdot T_{ij} + \lambda_3 \cdot R_{ij} \quad (13)$$

L_{ij} Among them, the first is the intensity of policy linkage between Zone i and Zone j ; the second is ecological attribute similarity; the third is governance time synchronisation; the fourth is resource sharing coefficient; and the fifth is a regulatory weight parameter. This function will flexibly change the order of policy intervention and cross-zone coordination intensity, prioritize the governance of high-sensitivity areas, and promptly carry out interventions in low-sensitivity areas based on available resources.

Determine if it is possible to implement the remediation plan in multiple areas simultaneously and coordinate geographical effort. Let denote the governance strategy set for Zone i and denote the strategy set for Zone j . The extent of linkage can be used to determine the coherence of the policy, as follows: C_{ij}

$$C_{ij} = \frac{|G_i \cap G_j|}{|G_i \cup G_j|} \quad (14)$$

C_{ij} Among them, the first represents the strategy coupling degree and has a range of [0, 1]; the second is the number of intersecting elements between the two zones' strategies, and the third is the total number of elements in the full set of strategies. A high degree of coupling indicates that the two areas are close together and can work together to share resources and institutions for joint development of the economy and society. This indicator system is to build a dynamic balancing mechanism for the orderly coordination and joint deployment of governance strategies in repair areas, thus improving the general response efficiency and resource utilization of the repair system.

3.4.4 Dynamic Adjustment and Rolling Optimization Mechanism

To improve the flexibility and adaptability of ecological restoration strategies for transmission

lines, a dynamic adjustment mechanism based on disturbance feedback should be added to support rolling optimisation of factor parameters and path planning. When ecological disturbance zones have abrupt changes or shifts in their long-term evolutionary trends, static strategy paths will not meet the actual restoration requirements. Therefore, the system needs to build a continuous-iteration optimal-strategy-evaluation function and dynamically reconstruct strategy sequences. Based on the sequence of strategy execution outcomes at time step t , the optimisation offset is determined by the following expression: $\Delta R(t)$

$$\Delta R(t) = \lambda \cdot [S(t) - \bar{S}(t - \delta)] \quad (15)$$

$\Delta R(t)$ $S(t)$ $\bar{S}(t - \delta)$ δ λ Among them, represents the adjustment size of the remediation strategy at the current time point, is the remaining index of the sensitive area after the current strategy is implemented, is the average residual value from the previous rolling period, is the length of the time window, and is the adjustment coefficient. The formula is used to dynamically assess the deviation in the ecological response after implementing the strategy, and thus serves as a trigger for strategy revision.

At the same time, a state-response error function is used to verify the stability of the updated plan during strategy path reconstruction. If the value is too high, then one of the two ways mentioned above is used for correction or adaptation. $\Phi(t)$ $\Phi(t)$ θ

$$\Phi(t) = \frac{1}{N} \sum_{i=1}^N |I_i(t) - I_i^*(t)| \quad (16)$$

$\Phi(t)$ N $I_i(t)$ $I_i^*(t)$ Among them, the first is the total response error of the repair area in the current rolling window; the second is the number of areas affected by the strategy; the third is the current indicator status of the area; and the fourth is the target desired state value. Determine how much the executed strategy path has deviated from the initial goal, and thus decide whether further modifications are necessary.

The dynamic differential function and response error function described above can automatically activate a parameter adjustment mechanism when the governance effect deviates too much. It can achieve rolling correction and optimised control of the strategy path to improve the adaptability of the system to complex ecological disturbances and enhance decision-making robustness.

3.4.5 Block-Level Governance Implementation Strategy

Identify the ecological disturbance area and a strategic plan, then show which governance solutions will be applied to each parcel through a specific map to implement orderly block-level remediation measures. Therefore, a function that maps instructions to zones can be built to link these zones with governance measures. The function controls the execution plan for the remediation block in the time period and is calculated as follows: $C(i, j)$ i j

$$C(i, j) = \alpha \cdot L_i + \beta \cdot P_j + \gamma \cdot M_{ij} \quad (17)$$

$C(i, j)$ i j L_i P_j M_{ij} α 、 β 、 γ Among them, it is the all-around execution instruction intensity of the repair block in the given time period; the perturbation level label of this block; the resource priority coefficient for the current time period; the compatibility score between governance measures and block attributes; and the weighted coefficients for the three categories

of factors. The formula will determine whether a block has immediate governance value and is feasible to implement at present.

To solve the problems of resource contention and space overlap in the repair work, an intervention density evaluation function has been added to monitor the overall distribution intensity of resources at any time. It is as follows: $\Psi(k)$

$$\Psi(k) = \sum_{i=1}^N \sum_{j=1}^T \delta_{ij}(k) \cdot R_{ij} \quad (18)$$

$\Psi(k)$ k N T $\delta_{ij}(k)$ i j R_{ij} . Among them, 'represents the system resource intervention density at time point ', 'denotes the total number of repair blocks', 'indicates the preset time series length', 'is a Boolean variable indicating whether block 's in execution state during time period', and 'signifies the resource demand weight for the corresponding repair measure'. The number of concurrent block operations shall be limited to prevent the system from being overloaded and damaging the environment due to prolonged use during construction.

Based on the above execution instruction functions and resource density control mechanisms, the system supports phased deployment and dynamic scheduling of block-level restoration plans. This will increase the accuracy and efficiency of governance implementation, ensure stable progress of large-scale ecological restoration tasks in multiple plots and over a long period, and coordinate the efforts of various departments.

4 Simulation Experiments and Results

4.1 Simulation Data Construction and Experimental Design Process

A simulated study area dataset of different ecological types was created to provide the data for technical verification of the multi-factor-driven ecological restoration zoning identification mechanism for transmission lines. Based on the land-use distribution in Jiangxi Province, the study area was set up, and a strip-shaped simulated corridor about 97.4 kilometres long was taken as the experimental sample area. This sample area has many kinds of landforms, such as forests, farmland, water bodies, grasslands and built-up areas. As shown in Figure 4, the spatial distribution of this ecological unit corresponds to the regional ecological conditions and has different levels of disturbance in the hilly area. According to topography and land-use conditions, the 236 grid-based ecological units were divided in this way. The data sources are a 10-metre resolution Digital Elevation Model (DEM), 2022 land use remote sensing images, nationally interpolated soil organic matter data, annual average hydrological monitoring data, and a human activity intensity distribution map built from Points of Interest (POI). Five ecological factors were selected per grid cell as the independent variables for the following model: topography, land use, soil, hydrology and human activity.

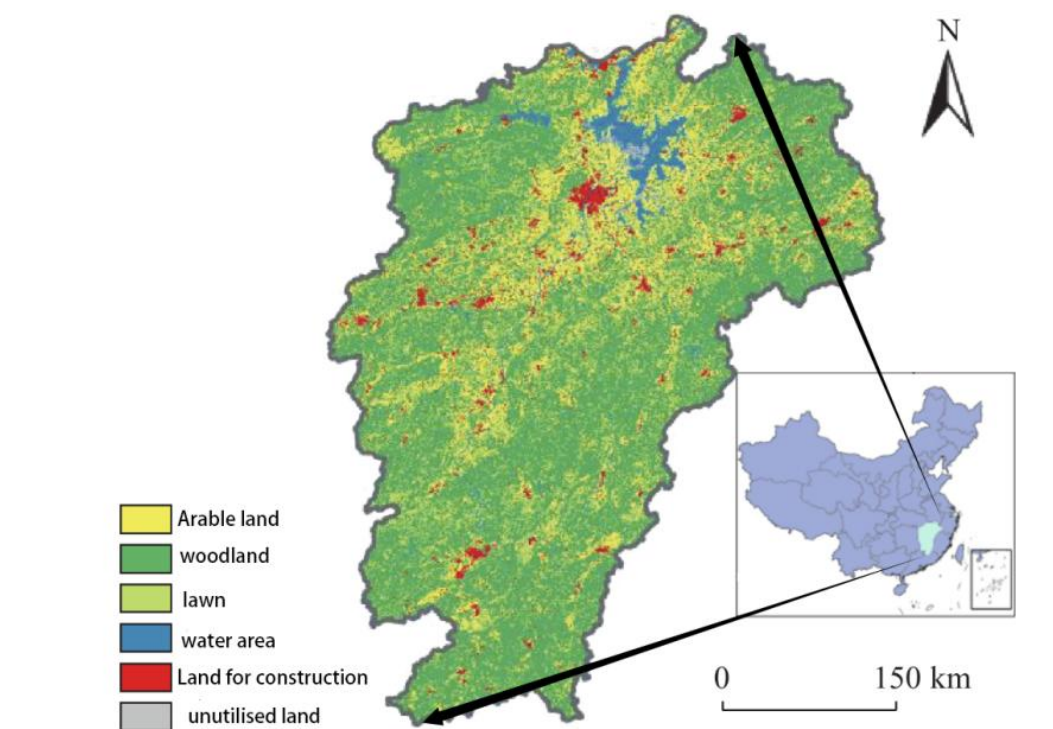


Figure 4: Distribution Map of Ecological Types in the Study Area

The locations of all kinds of ecological land use in the research area are shown in the map below, including agricultural land, forests, grasslands, water bodies and built-up areas. It has a general hill-basin structure and an uneven distribution of ecological zones. The different locations and forms of the land resources in the area will provide a geographic foundation for the construction of the multi-source factor model, disturbance characteristics, and management plans.

To improve the disturbance adaptability of the experiment, artificial construction trajectories, sudden meteorological disturbance locations, and historical patrol disturbance data have been added to form 117 multi-scenario evolutionary paths. GeoPandas and rasterio libraries were used in Python to construct the system for reading spatial data and rebuilding rasters. Factor fusion and weight allocation modules were used to calculate information entropy, and graph structure modelling employed NetworkX for adjacency relationship construction and edge weight calculation. The training stage set up a combined fuzzy C-means clustering and spectral clustering module, and the strategy matched library embedding 12 restoration technique templates and attribute vectors.

Stratified cross-validation is employed in the experimental workflow to randomly select 70% of the ecological units as the training set and set aside the remaining 30% for testing and validation. All experimental groups are set up in the same way and repeat the model five times to ensure the stability of the test results for generalisation. Finally, all the identification results, partition structures and strategy matching outputs will be exported to the platform's visualisation interface for a full basis of the subsequent effect evaluation and indicator analysis.

4.2 Comparison of Partition Recognition Accuracy and Stability Across Models

To verify both the effectiveness and applicability of the multi-source factor-driven ecological restoration partition recognition method for transmission lines, three comparative models were established: ① A traditional static clustering model (K-means); ② A single-factor-driven rule-

based partitioning model; and ③ The multi-source factor graph structure model (MFGM) proposed in this paper. The 236 ecological grid cells that had been built earlier covered the entire 97.4km line in the experiment. Several rounds of zoning modelling and strategy-response simulations have been conducted using disturbance evolution samples and comprehensive factor attributes. All models used the same training-testing partition structure and were set to five-fold cross-validation uniformly. Compare the Mean of the Performance Indicators.

Figure 5 is the partition boundary curves produced by the above models in a typical zoning task. It can be seen that the static clustering model has irregular changes in the smoothness of the boundary and will artificially divide continuous areas of landforms. A rule-based partitioning model will have fixed divisions and thus fail to consider the real distribution of the disturbance. On the other hand, the MFGM model establishes partition boundaries according to the graph's adjacency structure that has been derived through factor integration; thus, the resulting boundaries show a higher degree of continuity and aggregation with the actual ecological distribution.

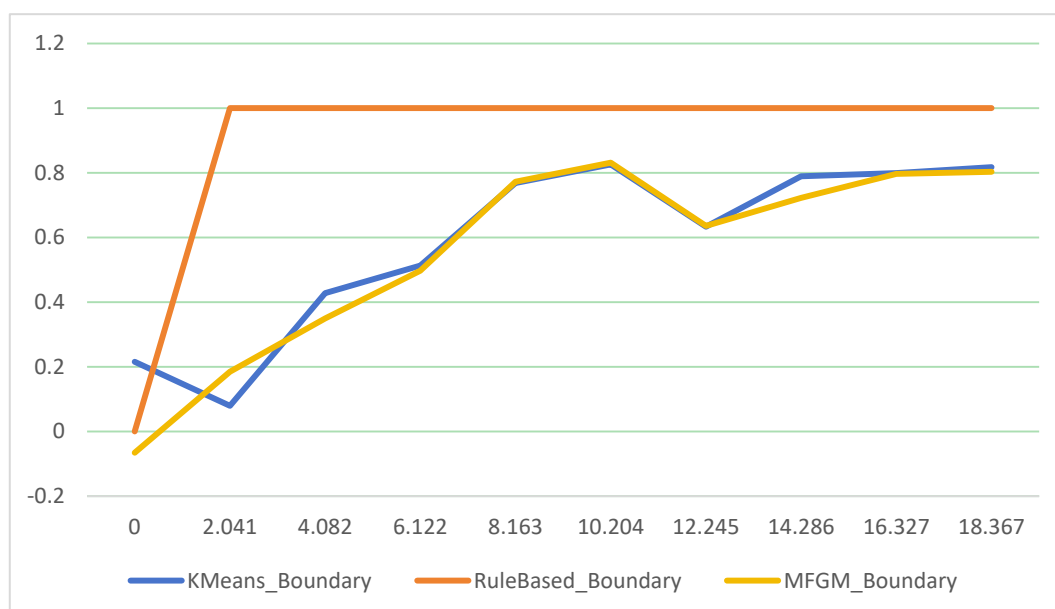


Figure 5: Comparison of Partition Boundaries for the three models in a typical sample area.

As shown in Figure 6, the fluctuations in the partition outputs across different phases of disturbance on working and non-working days are consistently the same. It can be seen that the partitioning structure of the MFGM model is stable under periodic disturbance inputs, and the average variation index is less than 0.12. On the other hand, the other two methods show considerable boundary fluctuations in response to high-frequency disturbances, and erroneous splitting and merging occur.

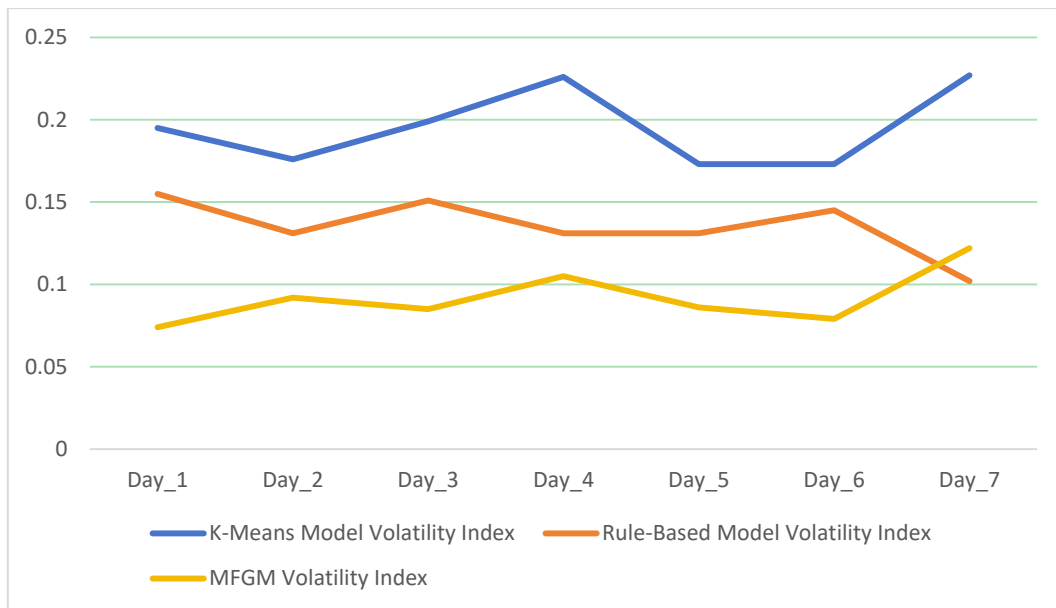


Figure 6: Trend Diagram of Zoning Boundary Shifts Under Various Disturbance Scenarios

As shown in Figure 7, the distribution curves of remediation strategy outputs for typical highly sensitive areas across the three model types are presented here in terms of response pathways. MFGM model has shown better results than the reference method in terms of the number of generated strategy types, distribution sparsity and target coupling, and is therefore more practical for field application.

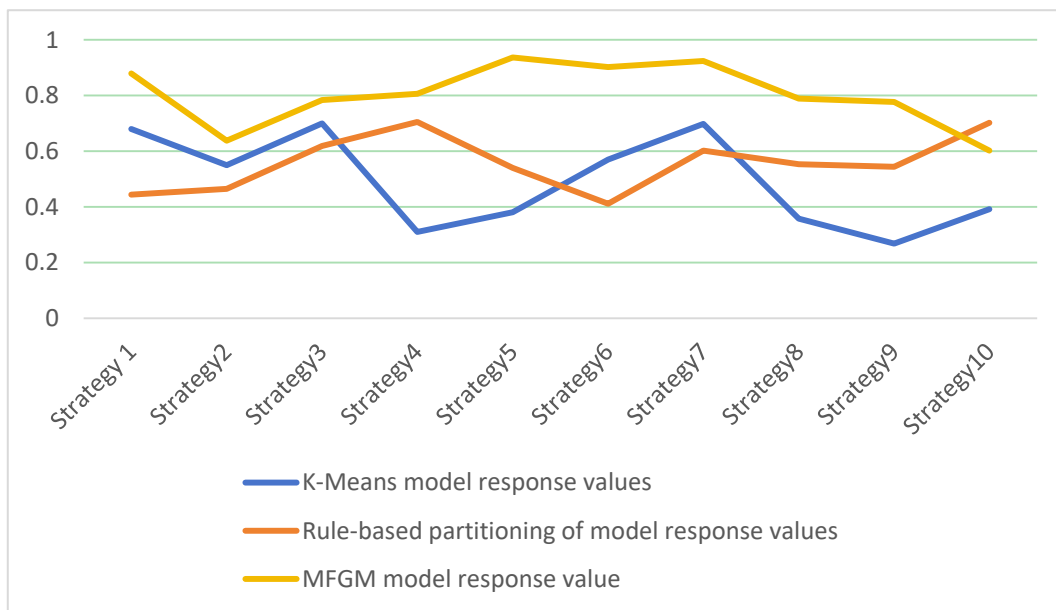


Figure 7: Output Response Diagram for Repair Strategy Types

As shown in Figure 8, the trend of regional feedback intensity after implementing the cascaded strategy. In the course of multi-round strategy iteration, the MFGM model has shown a more convergent and stable feedback trend, and its maximum response deviation has decreased at a faster rate than the other two models.

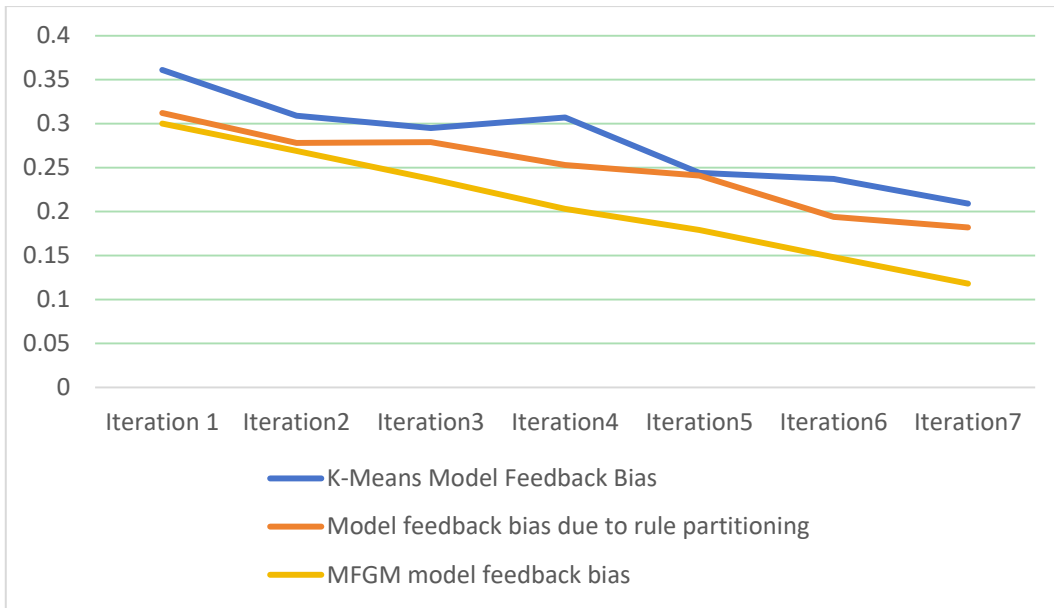


Figure 8: Curve Diagram of Changes in Strategy Iteration Feedback Intensity

As shown in Figure 9, the three main indicators of the five experimental rounds are presented here: mean accuracy, partition boundary coherence score and strategy execution hit rate. It can be seen from the above that the MFGM model is best among all models in terms of the above indicators and has a notable improvement in execution accuracy at the strategy-matching level.

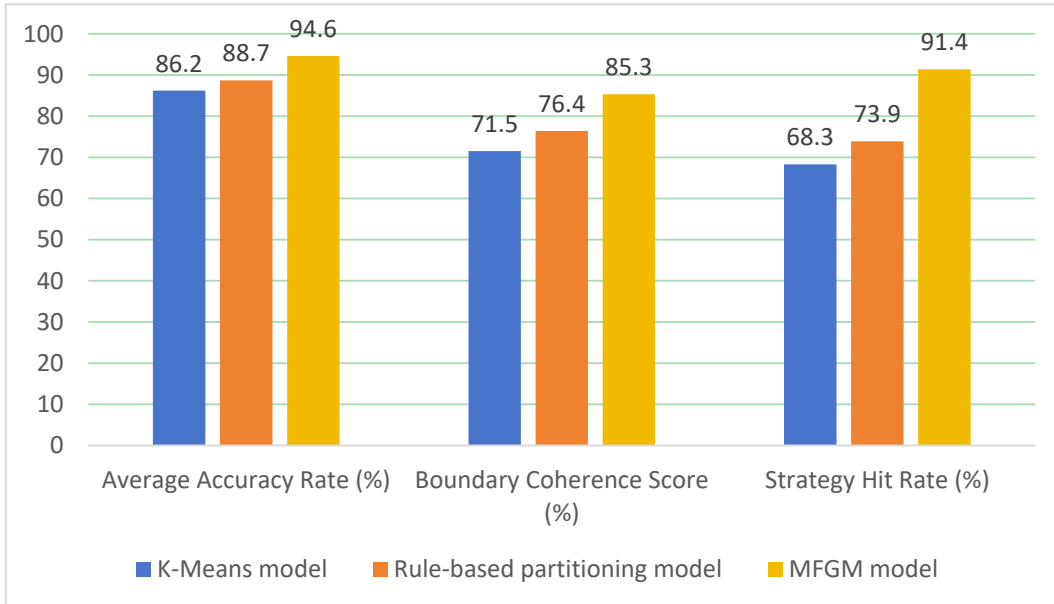


Figure 9: Bar chart of Partition Identification and Policy Matching metrics for the three model types

Table 2 presents the average performance indicators of the three models under five sets of experiments: accuracy, execution time, mean boundary deviation and maximum feedback offset. MFGM model had a 94.6% accuracy, an average execution time of less than 1.32 seconds, and a boundary deviation of 2.3%; it was significantly better than the baseline model.

Table 2: Comparison of Performance Metrics for the Three Models in Partition Recognition

Model	Average Accuracy Rate (%)	Average time taken (s)	Boundary deviation (%)	Strategy Feedback Offset (%)
K-means	86.2	1.01	6.4	8.1
Rule-based partitioning model	88.7	0.86	5.3	6.7
MFGM model	94.6	1.32	2.3	3.9

Anomalous Model behaviour was also observed in the experiment under specific circumstances. For example, in blocks with high topographical undulations and considerable hydrological disturbances, the rule-based partitioning model erroneously merged water source influence areas with marginal farmland, thus failing to implement the remediation plan. The MFGM model did not have this merging error and adjusted the weights of the edges dynamically; thus, it was more stable.

Overall, the above comprehensive analysis shows that the proposed model has improved partition identification accuracy, boundary coherence and adaptability of strategy deployment through the combined use of graph structure and multi-factor response mechanisms. It has good engineering feasibility and implementability. In the future, a temporal model and disturbance-prediction module can be added to enhance the dynamic environment performance of the model's feedforward control function.

5 Conclusions

The multi-source factor-driven ecological restoration partition identification model for transmission lines proposed here can achieve high-precision demarcation of damaged areas and restoration route suggestions in areas with difficult terrain by building a graph-structured adjacency relationship and a factor fusion mechanism. Across the 236 simulated grid cells, the model achieved an average accuracy of 94.6% in five rounds of experiments on representative plots and surpassed KMeans (86.2%) and rule-based partitioning (88.7%). Reduce the boundary deviation to 2.3% and increase the strategy hit rate to 91.4%. Under all kinds of disturbances, the structural change index of the model was consistently less than 0.12, it showed a strong feedback convergence trend and exhibited good stability and robustness.

The suboptimal performance of the traditional model in terms of boundary abruptness and strategy redundancy has been improved; thus, a more balanced achievement of all dimensions, including boundary coherence, strategy deployment sparsity and target coupling, is now possible. A graph structure can be employed to dynamically adjust and region-specific modelling to improve the joint identification of ecologically sensitive areas and high-disturbance zones. Although the model has response delays and misjudgements of boundary overlaps in some high-interference scenarios, it is still relatively promising for engineering applications. Increase the dimensions of the input factors in the subsequent studies, strengthen the closed-loop mechanism for regional disturbance prediction and strategy feedback, improve the generalisation ability of the model, and promote its application in the ecological governance of transmission lines.

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