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Risk Assessment of Distribution Lines in Typhoon Weather Considering Socio-economic Factors

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Abstract: In recent years, the frequent occurrence of typhoon weather has posed a significant threat to the stable operation of the distribution network in the southeastern coastal areas of China. Ensuring the safety of distribution lines is crucial for the normal functioning of the distribution network. Therefore, this paper proposes a risk assessment method for distribution lines in typhoon weather. Firstly, the risk assessment system for distribution lines is constructed by considering three perspectives: line structure, line state, and social economic factors. Secondly, the weight of each evaluation index is calculated using the analytic hierarchy process and CRITIC weight method. The cooperative game method is then employed to combine the calculation results, and the results are further optimized using variable weight theory. Finally, a cloud model-based risk assessment model for distribution lines is established. The analysis and calculation of distribution network data in a specific area indicate that the risk assessment level, which takes into account social and economic factors, is more accurate compared to other methods discussed in this paper. It is observed that the multi-model approach yields higher accuracy than the single-model approach. Therefore, the proposed method holds significant reference value for evaluating the risk level of distribution lines.

Keywords: distribution lines; typhoon weather; risk assessment; cooperative game; cloud model; variable weight theory

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1. Introduction

Typhoons pose a significant security threat to coastal power grids, resulting in severe social and economic losses [1,2]. To mitigate the impact of typhoon disasters, conducting advanced risk assessments and implementing appropriate measures on coastal distribution networks is crucial. Power outages during typhoon events are primarily caused by cascading failures in distribution lines [3]. Hence, conducting risk assessments on distribution lines under typhoon conditions plays a vital role in preventing distribution network disasters.

Several scholars have conducted research on the evaluation index system of distribution line vulnerability [4]. Ref. [5] summarizes the application of the maximum flow theory method and the improved betweenness method in identifying vulnerable lines based on complex network theory. In Ref. [6], the line's apparent power is used as the line flow, and the electrical in-degree and out-degree centrality are proposed to identify vulnerable lines. However, the influence of the nodes at both ends of the line on the line vulnerability assessment is not considered. Ref. [7] establishes a comprehensive line vulnerability index based on grid topology information, taking into account the node information at both ends of the line. In Refs. [8,9], an improved transmission betweenness method is proposed to quantify the vulnerability of transmission lines. This method combines edge betweenness and power transmission distribution factor. Ref. [10] extends the traditional structural vulnerability index by considering factors such as the overall load rate of the system and voltage margin. It establishes the node vulnerability assessment index. However, the aforementioned literature only focuses on the risk of distribution lines during typhoon weather, considering topology and network operation. It overlooks socio-economic factors like population density and economic scale along the line's path.

The risk assessment of distribution lines involves multiple indicators and their respective weights to comprehensively assess the risk level. In the literature [10–13], the entropy weight method and analytic hierarchy process are introduced to evaluate the vulnerability of distribution network nodes. In Ref. [14], the evaluation index was scored using the analytic hierarchy process and fuzzy evaluation method to select the optimal site for a photovoltaic station. In a study by Ref. [15], a distribution line fault early warning model was developed using the analytic hierarchy process. Another study by Ref. [16] utilized the fuzzy analytic hierarchy process and entropy method to determine the weights of the indexes. They also constructed a multi-index fusion model for evaluating the vulnerability of distribution line nodes, which addressed the limitations of using a single index for evaluation. However, these studies did not consider the influence of sudden changes in line state values on the weights during typhoon weather.

In light of the aforementioned issues, this study proposes a risk assessment method for distribution lines during typhoon weather that takes into account both the electrical characteristics of the lines and the socio-economic influencing factors. A comprehensive evaluation index system for the vulnerability of distribution lines is established. The weights of each index are determined through a combination of subjective analytic hierarchy process and objective CRITIC weight method. The cooperative game method is used to obtain the combination weight, which is then optimized using the variable weight theory to adjust the weight of each index appropriately. Finally, the risk level assessment of distribution lines is conducted based on the cloud model theory [17].

2. Vulnerability Evaluation Index System of Distribution Lines

This paper comprehensively examines the three levels of line structure, line status, and socio-economic factors. It also establishes an index system for assessing the risk of distribution lines during typhoon weather, as depicted in Figure 1.

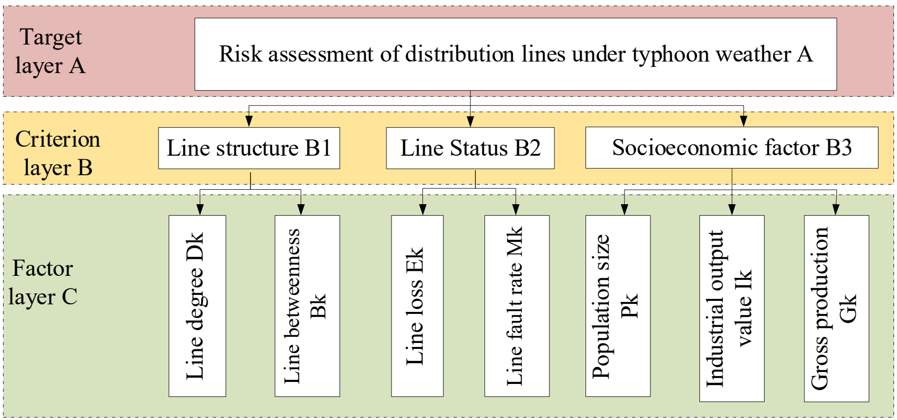

Figure 1. Risk assessment index system of distribution network in typhoon weather.

2.1. Line Structure

2.1.1. Line Degree

The degree is a measure of the importance of the connection between a node and other nodes in the topology. In the case of distribution lines, the degree of importance of the line is higher when the nodes at both ends of the line are more important.

Based on the traditional node degree, this paper considers the node input power of the distribution line [12], so the line degree is defined as:

$$\mathrm{D}_{ki} = \mathrm{P}_i \sqrt{\mathrm{D}_i \sum_{j \in \mathrm{V}} \mathrm{D}_j} \tag{1}$$

D_i represents the number of edges connected to the node i; V represents the set of all nodes adjacent to the node i; P_i indicates the actual power flowing into the node i.

2.1.2. Line Betweenness

To assess the power flow propagation in the line, we consider the law of power flow propagation between nodes. In this study, we utilize the following expressions for calculation:

$$B_e(m,n) = \left| \sum_{i \in G, j \in L} \omega_{ij}(k) \mathrm{P}_{mn}(i,j) \right| \tag{2}$$

In the equation, $\omega_{ij}(k)$ is the current value transmitted by line k when a unit current source is applied between the bus node i and the load node j, assuming that the active power transmitted from the node m to the node n is $\mathrm{P}_{mn}(i,j)$.

The traditional betweenness calculation, which relies on the shortest path, is not applicable to distribution networks due to their radial open-loop operation. Therefore, it is more practical to use $\omega_{ij}(k)$ instead of the shortest path.

2.2. Line Status

2.2.1. Line Failure Rate

The failure rate of distribution lines under typhoon weather is strongly influenced by the typhoon wind field. In this study, we utilize the enhanced Batts wind field model [18] to estimate the wind speed along the distribution line. The wind speed at a specific point is determined by the geographical location of the typhoon center and the point itself. The relationship between the probability of a single tower failure in the distribution line and the typhoon wind speed can be represented by an exponential curve function [19]:

$$\lambda s = \begin{cases} 0, \mathrm{V} \in [0, \mathrm{V}_{\min}] \\ e^{\mathrm{K}(\mathrm{Vz} - 2\mathrm{Vmin})}, \mathrm{V} \in [\mathrm{V}_{\min}, 2\mathrm{V}_{\min}] \\ 1, \mathrm{V} \in [2\mathrm{V}_{\min}, \infty] \end{cases} \tag{3}$$

Among them, V_z is the wind speed value of the typhoon at a certain moment, and $\mathrm{V}_{\min}$ is the design wind speed of the tower. According to the design wind speed standard of the 35 kV distribution line, the value of this paper is 30 m/s, and the value range of the parameter K is (0, 0.4).

Several towers form a distribution line. According to the reliability mathematical model of the series system, the fault probability of a distribution line k is [18]:

$$\mathrm{M}_k = 1 - \prod_{s=1}^{\mathrm{N}_k} (\exp(-\frac{\lambda_s}{1 - \lambda_s})) \tag{4}$$

2.2.2. Line Loss Value

In the identification process of vulnerable distribution lines, the electricity sales loss caused by the fault and its consequences are multiplied to evaluate the vulnerable lines, that is:

$$\mathrm{E}_k = \mathrm{U}_k \mathrm{Q}_k \tag{5}$$

In the equation E_k is the loss value of the line k caused by the typhoon disaster. U_k represents the unit loss cost when the fault occurs in the line k, and Q_k represents the load loss of the fault load node caused by the fault of the line k. According to the importance of load nodes, the economic losses of average unit power can be divided into two categories, namely 0.79 CNY per kilowatt hour and 0.57 CNY per kilowatt hour.

2.3. Socio-Economic Factors

2.3.1. Population Size

The failure of distribution lines during typhoon weather can result in power outages within a specific time range in the region. This can significantly impact the lives of the population in the area and may even lead to casualties. This indicator highlights the significance of routes in the region based on population density. The importance of a line passing through an area is directly proportional to the population density, and a higher weight value is assigned to such lines.

2.3.2. Industrial Output Value

In order to mitigate economic losses, enterprises in the region may need to halt production during typhoons, which can have an impact on the region's economic development to some extent. The industrial output value serves as an indicator of the significance of the lines passing through the region in terms of industrial production. A higher industrial output value indicates greater importance of the line passing through the region and, therefore, assigns a higher weight value to it.

2.3.3. Gross Production

In addition to industrial production, the production of agriculture and the tertiary industry may also be affected by certain procedures during typhoon weather. The impact of typhoons varies depending on the industrial structure of different regions. The gross domestic product (GDP) is a reflection of the significance of the economic route passing through a region. The higher the economic aggregate, the more important the route becomes, and thus, it is assigned a greater weight value.

3. Integrated Assessment Model

In this paper, we combine the subjective analytic hierarchy process and CRITIC weight method to comprehensively determine the weight coefficients of the seven indicators. We utilize the cloud model theory to construct the evaluation model and compare the standard cloud model with the comprehensive cloud model to determine the final risk level. The framework of the risk assessment model is depicted in Figure 2.

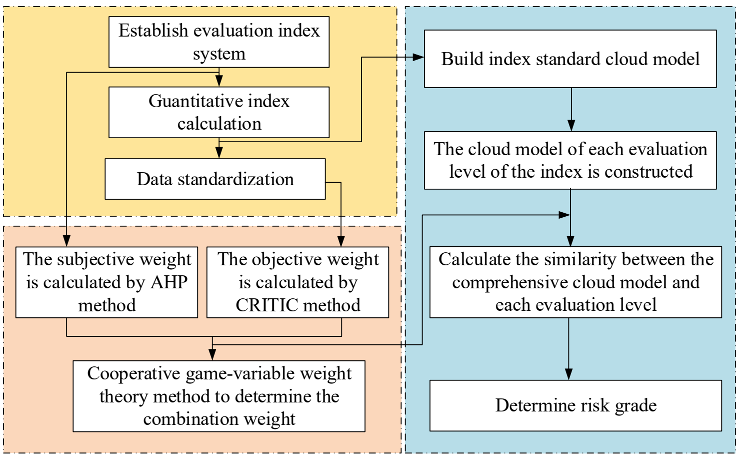

Figure 2. Evaluation model framework diagram.

3.1. AHP Method

The Analytic Hierarchy Process (AHP) [20] is a multi-objective decision analysis method that combines qualitative and quantitative analysis. It utilizes pairwise comparison to assess the judgment of experts and determine the weight of each element. The calculation steps of the AHP are as follows [21]:

(1) According to the expert experience, the nine-scale method is used to construct the judgment matrix:

$$B(b_{ij})_{m\times n} = \begin{pmatrix} b_{11} & \cdots & b_{1m} \\ \vdots & \ddots & \vdots \\ b_{m1} & \cdots & b_{mn} \end{pmatrix} \tag{6}$$

Among them, b_{ij} represents the importance of indicator i to indicator j.

(2) Hierarchical single sorting. After passing the consistency test of the judgment matrix, the normalized feature vector is used as the weight vector of this level:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{7}$$

n is the index number of this layer. $\lambda_{\max}$ is the maximum eigenvalue of the judgment matrix.

$$CR = \frac{CI}{RI}\begin{cases} < 1 \text{ The judgment matrix is consistent} \\ \geq 1 \text{ The judgment matrix is inconsistent} \end{cases} \tag{8}$$

In the equation, CR is the random consistency ratio of the comparison matrix; CI is the general consistency index; RI is the random average consistency index; when CR < 0.1, the judgment matrix is considered to meet the consistency. If CR $\geq$ 0.1, the matrix needs to be modified until the condition is satisfied.

(3) Hierarchical total sorting is used to calculate the weight vector of the scheme layer to the target layer and test its consistency. The decision is made based on the total ranking weight vector, taking into account the weight of each index of the analytic hierarchy process:

$$\omega_j = \frac{U_j}{\sum\limits_{j=1}^{7} U_j} \tag{9}$$

3.2. CRITIC Method

The CRITIC weight method [22] is used to comprehensively measure the weight of evaluation indicators based on their volatility and conflict and represents the amount of information using the product of the two. The specific steps of the CRITIC weight method are as follows [23]:

(1) Using data standardization processing:

$$z_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \tag{10}$$

(2) Calculate the variability quantitative index of the index j and other indicators. The standard deviation is used to represent the contrast of the four evaluation indexes of line failure rate, line loss value, line betweenness, and line degree. The calculation equation is shown in Equation (11). The study uses 32 lines as the evaluation object, so the value range of parameter i is [1, 32].

$$\begin{cases} \overline{x_j} = \frac{1}{32}\sum\limits_{i=1}^{32} z_{ij} \\ S_j = \sqrt{\frac{\sum\limits_{i=1}^{32}(z_{ij} - \overline{x_j})^2}{32}} \end{cases} \tag{11}$$

where $\overline{x_j}$ is the mean value of the index j, and S_j is the standard deviation of the index j.

(3) Seven evaluation indicators have been established above to further calculate conflicting quantitative values between them. Calculate the conflict quantitative value between the index j and other evaluation indexes. The calculation equation is:

$$\begin{cases} \mathrm{r}_{ij} = \frac{\mathrm{cov}(Z_i, Z_j)}{\sigma_i \sigma_j} \\ R_j = \sum\limits_{i=1}^{7} (1 - \mathrm{r}_{ij}) \end{cases} \tag{12}$$

In the equation, r_{ij} is the correlation coefficient between the index i and the evaluation index j. $\mathrm{cov}(Z_i, Z_j)$ denotes the covariance between columns i and j of the standard matrix Z; σ_j is the standard deviation of each index.

(4) Calculate the amount of information contained in the indicator j.

$$C_j = S_j R_j \tag{13}$$

(5) Calculate the weight ω_j of the index j.

$$\omega_j = \frac{C_j}{\sum\limits_{j=1}^{7} C_j} \tag{14}$$

3.3. Cooperative Game-Variable Weight Theory Combination Weighting

3.3.1. Cooperation Game Model

By minimizing the deviation between the combination weight and the basic weight [24], the combination weighting is more reasonable. Two groups of basic weights are obtained by using analytic hierarchy process and CRITIC weight method. According to the method of cooperative game [25], the combination coefficients $\lambda_1{}^*$ and $\lambda_2{}^*$ are solved. Finally, the coefficients are substituted into the combination weight $W_j{}^*$.

The objective function is as shown in Equation (15):

$$\min \left\| \sum_{k=1}^{2} \lambda_k W_k{}^{\mathrm{T}} - W_k \right\|_2 \tag{15}$$

According to the differential principle, the solution of the objective function is transformed into solving linear equations:

$$\begin{bmatrix} W_1 W_1{}^{\mathrm{T}} & W_1 W_2{}^{\mathrm{T}} \\ W_2 W_1{}^{\mathrm{T}} & W_2 W_2{}^{\mathrm{T}} \end{bmatrix} \begin{bmatrix} \lambda_1 \\ \lambda_2 \end{bmatrix} = \begin{bmatrix} W_1 W_1{}^{\mathrm{T}} \\ W_2 W_2{}^{\mathrm{T}} \end{bmatrix} \tag{16}$$

The obtained linear combination coefficients λ_1 and λ_2 are standardized:

$$\begin{cases} \lambda_1{}^* = \frac{|\lambda_1|}{|\lambda_1| + |\lambda_2|} \\ \lambda_2{}^* = \frac{|\lambda_2|}{|\lambda_1| + |\lambda_2|} \end{cases} \tag{17}$$

Further, the combined weight coefficient is:

$$W_j{}^* = \lambda_1{}^* W_1 + \lambda_2{}^* W2 \tag{18}$$

3.3.2. Variable Weight Theory

The comprehensive weight obtained from the above calculation is a constant weight, which remains unchanged once determined for each index. However, the power flow distribution of distribution lines changes with the variation in typhoon wind speed. This change becomes particularly significant when individual indicators reach critical values. In such cases, the constant weight fails to accurately assess the risk of the region, resulting in unreasonable assessment results. To address this limitation, this paper adopts the variable weight theory to reflect the balance of the state of each factor in the comprehensive evaluation [26]. The calculation equation is as follows:

$$\omega_i{}^v = \frac{W_j{}^* x i^{\partial-1}}{\sum\limits_{p=1}^{n} W_p{}^* x_p{}^{\partial-1}} \tag{19}$$

In the equation, $\omega_i{}^v$ is the variable weight of the index i; $W_j{}^*$ is the index j combination weight; x_i is the index value i; ∂ is an equilibrium function, and its value depends on the relative importance of each comprehensive state quantity. The value range is [0, 1]. The smaller the value, the higher the attention to the corresponding state quantity. [27]. For the line structure and line state index, it can reflect the operation state of the distribution line and the empirical value $\partial = 0.3$; for the social factor index, it can reflect the economic loss and the number of people affected by the typhoon when the distribution line is affected by the typhoon, which needs to be paid attention to, and the empirical value $\partial = 0.2$.

4. Cloud Model

4.1. Definition of the Cloud Model

The cloud model can realize the mutual transformation between qualitative concept and quantitative representation, and its properties are represented by three digital features: expectation Ex, entropy En, and hyper entropy He [28]. The expectation En is the center of the cloud, and the entropy En represents the degree of dispersion of the qualitative concept, which further reflects the relationship between the randomness and fuzziness of the qualitative concept [29]. He is the uncertainty measure of entropy. Taking the cloud model with digital feature $(1, 0.09, 0.007)$ as an example, a one-dimensional cloud model of 5000 cloud droplets is constructed, as shown in Figure 3.

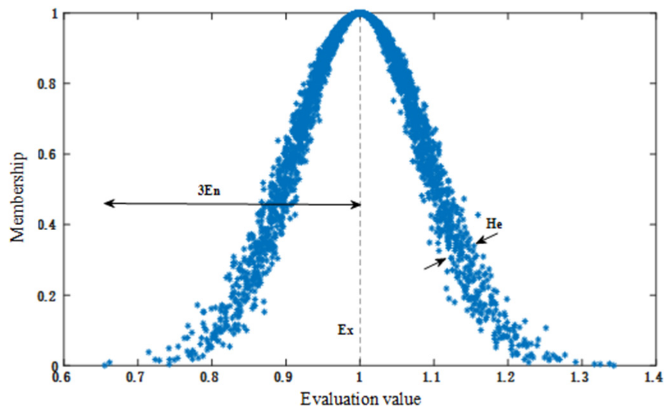

Figure 3. One-dimensional cloud model.

Suppose that U is used to represent a universe of discourse described by quantitative values; $C(Ex, En, He)$ is a qualitative concept described by qualitative language in U space. If U has a quantitative value x, x is a random realization of C, then the membership degree of x to C is expressed as [30]:

$$\mu(x) = \exp\left(-\frac{(x - Ex)^2}{2(En')^2}\right) \tag{20}$$

The forward cloud generator is a mapping from qualitative concepts to quantitative representations, while the reverse cloud generator is a transformation from quantitative concepts to qualitative concepts. Figure 4 illustrates the cloud generator.

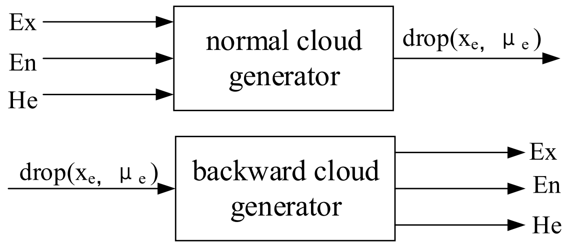

Figure 4. Cloud generator.

4.2. Establish a Standard Cloud Model

The risk level of distribution lines is divided into 'extremely low risk', 'low risk', 'medium risk', 'higher risk', and 'highest risk'. According to the golden ratio segmentation method, the comments are graded [30], and the numerical characteristics of the evaluation standard cloud are calculated, as shown in Table 1. The standard cloud model is shown in Figure 5.

Table 1. Eigenvalues of standard cloud model.

Risk Slogans	Digital Characteristic
Extremely low risk	(0.000, 0.103, 0.0013)
Low risk	(0.309, 0.064, 0.0080)
Medium risk	(0.500, 0.039, 0.0050)
Higher risk	(0.691, 0.064, 0.0080)
Highest risk	(1.000, 0.013, 0.0130)

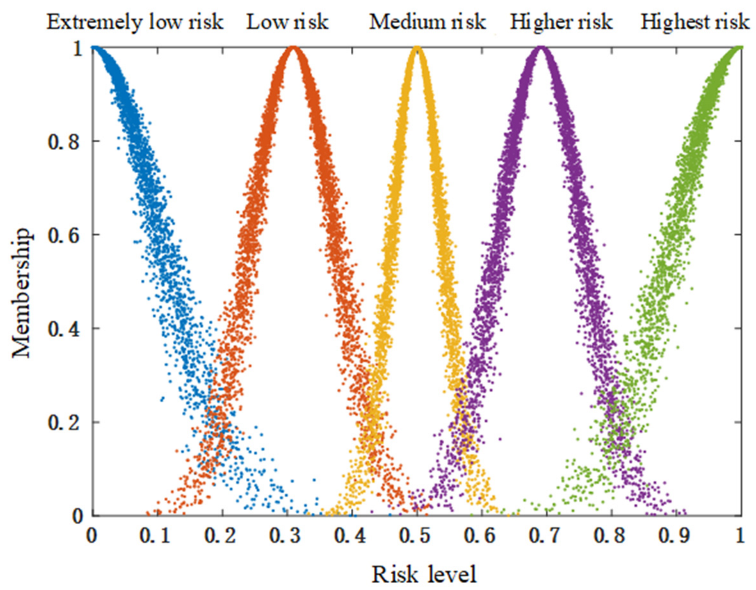

Figure 5. Risk assessment standard cloud model diagram.

To address the challenge of distinguishing the relative position between the comprehensive evaluation cloud and the standard cloud, this study proposes a method to calculate the similarity and obtain the final risk evaluation level. The vector of the standard cloud is expressed as $\vec{F_i} = (\mathrm{Ex}_i, \mathrm{En}_i, \mathrm{He}_i)$, and the vector of the integrated cloud is expressed as $\vec{F_j} = (\mathrm{Ex}_j, \mathrm{En}_j, \mathrm{He}_j)$. The similarity is calculated according to the following equation [31], and sim is the similarity function. According to the principle of maximum similarity, the risk level is finally evaluated.

$$\mathrm{sim}(i,j) = \frac{\vec{F_i} \cdot \vec{F_j}}{\|\vec{F_i}\| \cdot \|\vec{F_j}\|} \tag{21}$$

In order to simplify the calculation results of the similarity function, D*i* is used in this paper. $D_1 \sim D_5$ is used to represent the similarity between the risk value of the comprehensive cloud and the standard cloud from extremely low to extremely high.

5. Experimental Evaluation and Discussion

5.1. Experimental Model and Data

The landing path and time of Typhoon Muifa [32], as well as the layout of the distribution line system [33], are shown in Figure 6, using 'Severe Typhoon Muifa' as an example. The maximum wind speed, central pressure, moving speed, and landing path data of the typhoon center were obtained from the typhoon network of the Central Meteorological Observatory.

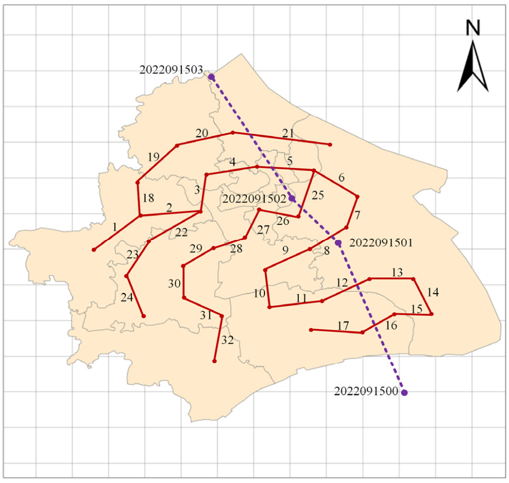

Figure 6. Distribution line system and typhoon path.

The population, total area, GDP, and total industrial output value of the study area were obtained from the statistical yearbook of the city (2021) and the statistical yearbook of each county [34]. The data were classified into ten grades using the natural discontinuity point classification method, with an assignment interval of [0, 1]. The weight value increases as the color gets darker. Figure 7 shows the population density of the region, Figure 8 shows the industrial output value, and Figure 9 shows the GDP.

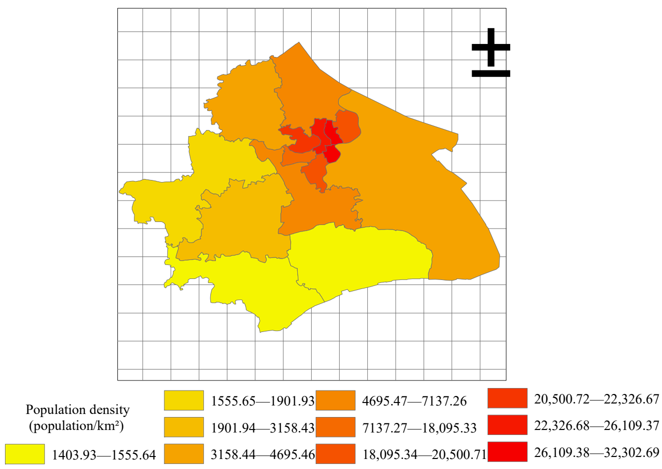

Figure 7. Population density map of a certain area.

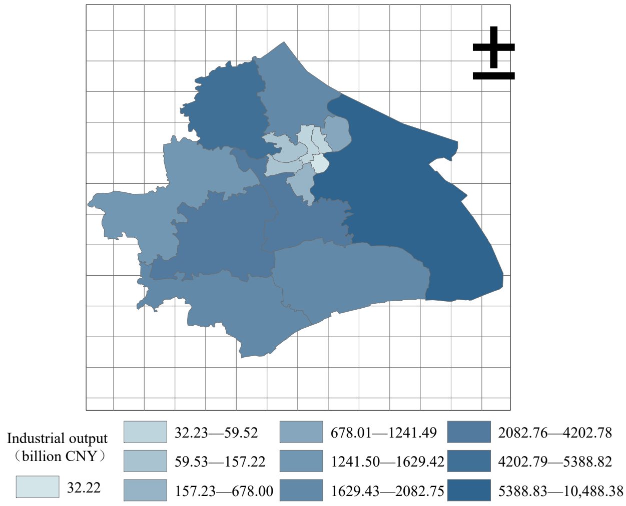

Figure 8. Map of the distribution of total industrial output value in the region.

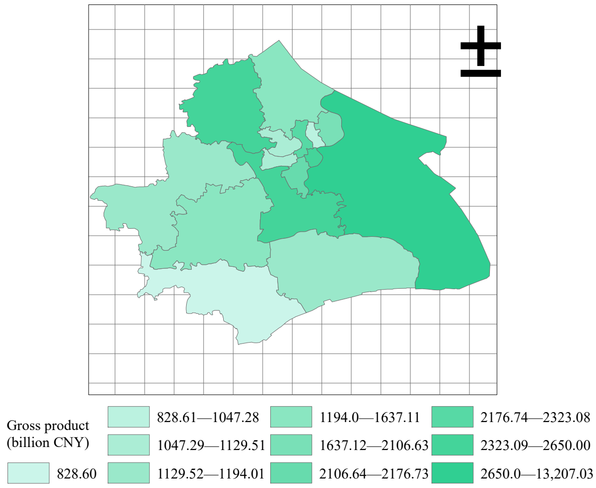

Figure 9. Map of the distribution of GDP in the region.

5.2. Weight Calculation

(1) The calculation results of subjective and objective weighting methods.

According to the equation, the results of the two weighting methods are calculated as shown in Table 2.

Table 2. Subjective and objective weight results.

Evaluation Index	AHP Weight Coefficient	CRITIC Weight Coefficient
D_k	0.1039	0.1132
B_k	0.2079	0.1380
E_k	0.1317	0.1514
M_k	0.0658	0.1126
P_k	0.0891	0.1701
I_k	0.1338	0.1467
G_k	0.2676	0.1681

(2) Calculate the combined weight.

According to the Equations (15)–(17), the combined weight coefficient is calculated as:

$$\begin{pmatrix} \lambda_1{}^* \\ \lambda_2{}^* \end{pmatrix} = \begin{pmatrix} 0.9780 \\ 0.0220 \end{pmatrix}$$

According to Equations (18) and (19), the combined weight coefficients of the four evaluation indexes are obtained as shown in Table 3.

Table 3. Constant weight and variable weight coefficient.

Evaluation Index	Combined Weight Coefficient	Variable Weight
D_k	0.1041	0.1428
B_k	0.2064	0.2387
E_k	0.1321	0.1632
M_k	0.0668	0.0940
P_k	0.0909	0.0901
I_k	0.1341	0.0793
G_k	0.2653	0.1919

The weight results of the factor layer and the criterion layer are shown in Figure 10.

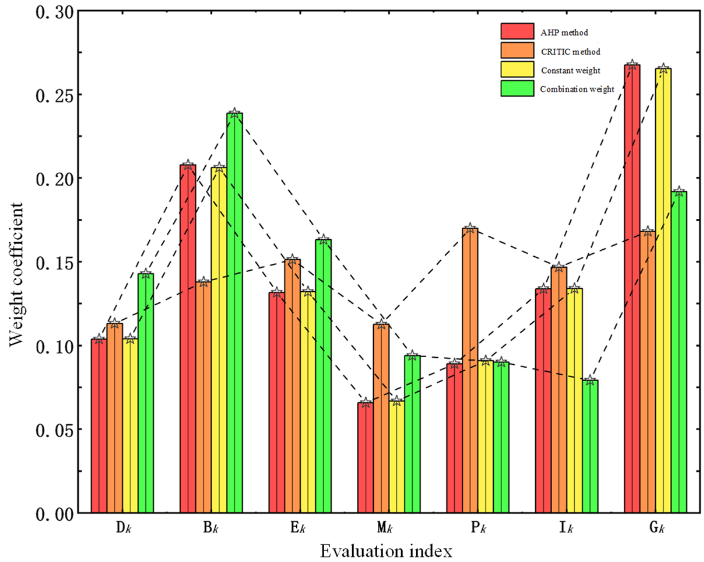

Figure 10. Evaluation index layer weight comparison result diagram.

The criterion layer weight comparison result diagram are shown in Figure 11.

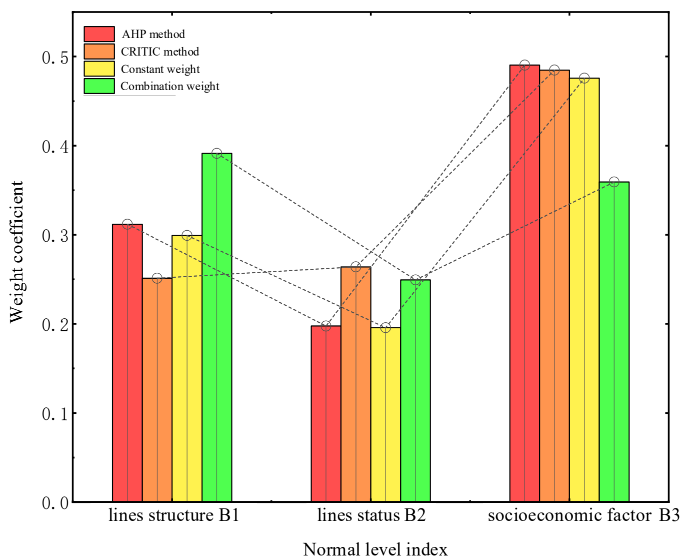

Figure 11. Criterion layer weight comparison result diagram.

5.3. The Cloud Model of Each Index Is Constructed

The calculation results are shown in Table 4.

Table 4. Numerical characteristics of the criterion layer.

Normal Level Index	Digital Features of Criterion Layer
line structure B1	(0.6848, 0.1240, 0.0295)
line status B2	(0.6529, 0.1113, 0.0045)
socio-economic factor B3	(0.3917, 0.0760, 0.0560)

Figure 12 illustrates a comparison diagram between the cloud model of the criterion layer and the standard cloud model based on the numerical characteristics of the criterion layer shown in Table 4.

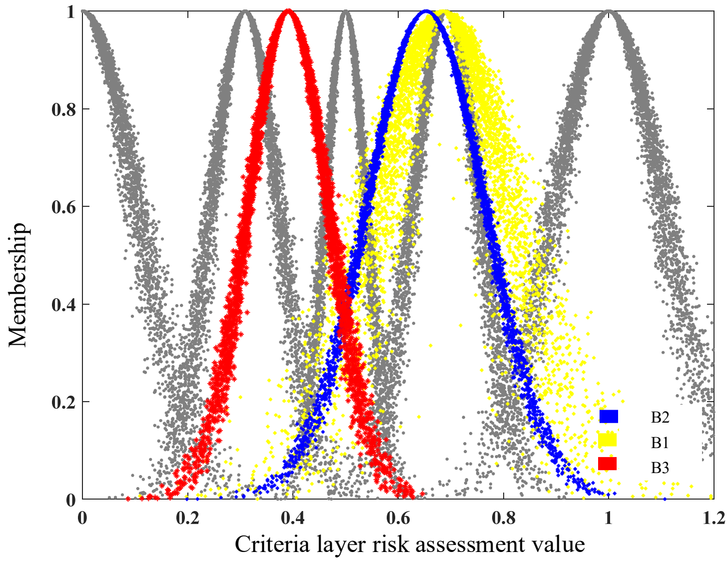

Figure 12. Cloud model diagram of criterion layer.

By applying the criterion layer and the variable weight coefficient, the digital eigenvalues of the comprehensive cloud model can be determined. The cloud model representing the target layer is illustrated in Figure 13. The characteristic value of the comprehensive cloud model is $(\mathrm{Ex}, \mathrm{En}, \mathrm{He}) = (0.057, 0.1052, 0.0354)$.

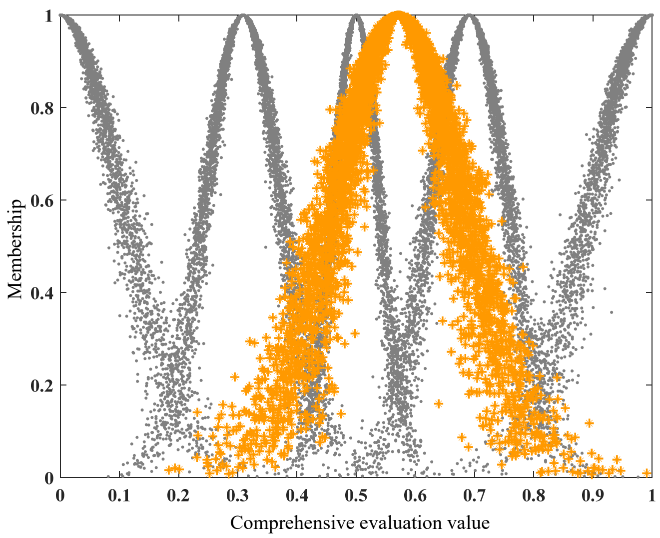

Figure 13. Target stratus cloud model.

In order to further accurately judge the risk level of the distribution line, the similarity between the cloud models is calculated by Equation (21). The similarity calculation results of the comprehensive cloud model and each standard cloud model are as follows: $D_1 \sim D_5$, the calculation results are $D_1 = 0.1867$, $D_2 = 0.9780$, $D_3 = 0.9935$, $D_4 = 0.9949$ and $D_5 = 0.9909$. According to the calculation results, $D_4 > D_3 > D_5 > D_2 > D_1$. The evaluation results indicate a higher risk level, as seen in the comprehensive cloud model diagram. Therefore, early warning measures should be implemented for the distribution line. To further validate the effectiveness of the method proposed in this paper, the AHP method and CRITIC method are combined with the cloud model separately, resulting in a medium risk assessment level. The cloud model method, which considers social and economic factors and variable weight theory, aligns better with the actual situation. The comparison results of the model evaluation are presented in Table 5.

Table 5. Model comparison results.

Model	Digital Characteristic	Evaluation Grade	Actual Grade
AHP method–cloud model	(0.5345, 0.0076, 0.0053)	Medium	Higher
CRITIC method–cloud model	(0.5348, 0.0980, 0.0133)	Medium	Higher
model in this paper	(0.5715, 0.1052, 0.0035)	Higher	Higher

5.4. Discussion

This paper first establishes seven distribution line vulnerability evaluation indexes from the three aspects of line structure, line status, and socio-economic factors and uses the method of cooperative game-variable power theory to optimize the assignment results of the subjective assignment method and objective assignment method and, finally, uses the cloud model to realize the assessment of the risk level. The experimental results show that when a typhoon occurs, the risk level of the region is 'higher risk', which is consistent with the actual situation and can truly and objectively reflect the risk level of the distribution lines in the region.

First, compared with existing studies, this paper takes into account the impact of socio-economic factors on risk assessment when establishing evaluation indicators. When a typhoon occurs, if a line is located in a densely populated area with high economic output value, it will bring serious casualties and economic losses if it is disturbed by the typhoon; therefore, even if the structure and operation of the line are at a medium level, it should be given some attention; if the structure and operation of the line are in a dangerous state, it is more important to combine the socio-economic factors to make an accurate risk level assessment. Therefore, it is one-sided to analyze only the structure and operation status of distribution lines.

Secondly, this paper uses cooperative game combined with the variable weighting theory method to optimize the basic assignment result. This paper adopts the cooperative game method to consider the imbalance between the data, avoiding the subjectivity of the traditional linear weighting method; on this basis, this paper adopts the variable weighting theory to optimize the result, taking into account the problem of sudden changes in the distribution of tidal currents of the distribution line due to the typhoon, and gives different values of equilibrium function to the evaluation indexes to further optimize the experimental results.

Finally, through the comparative analysis of the single evaluation model and the comprehensive model proposed in this paper, it can be concluded that both the method of this paper and the traditional method consider that the distribution line in this area is risky, but the results of the model in this paper are more in line with the actual situation, and it is considered that the distribution line has a higher risk level, as shown in Table 5.

The research in this paper also has certain limitations, not fully considering the impact of a small area of building shading on the risk assessment of distribution lines, and it is hoped that fieldwork can be carried out so that more accurate data can be obtained and a more accurate risk assessment of the study area can be realized.

6. Conclusions

This paper presents a distribution line risk assessment model based on variable weight and cloud models to address the shortcomings of the current evaluation index and model. The proposed model takes into account not only the physical structure of the distribution line but also the social and economic factors of the area where the distribution line is located as evaluation indices. By incorporating both power and social–economic systems, the evaluation model can effectively assess the risk level of the distribution line. The cloud model enables the conversion of qualitative and quantitative concepts, facilitating the visualization of risk levels in distribution lines. The results of the example show that the proposed method can realize the judgment of the risk level of the distribution line and can be used to guide the typhoon disaster prevention of the distribution network in the coastal area.

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