ISSN 2616-5872 Vol. 7, Issue 1: 55-62, DOI: 10.25236/AJEE.2025.070107

Construction of Urban Typhoon Risk Assessment System Based on CRITIC and TOPSIS Model: A Case Study of Wenzhou City, Zhejiang Province

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Abstract: *Urban typhoon risk assessment is important in urban disaster prevention and insurance assessment. Most of the existing studies on urban typhoon risk assessment systems build assessment models from a subjective perspective. In contrast, few studies mine information from existing historical data and build assessment models from it. In this study, a set of urban typhoon risk assessment systems was constructed by combining the improved CRITIC method and TOPSIS with 11 correlation indicators, including average daily rainfall and river network density, in the areas under the jurisdiction of Wenzhou City, Zhejiang Province. This system was used to evaluate the risk index of each region in Wenzhou, and the proportions of high risk, medium risk, and low risk were obtained as 26.14%, 41.25%, and 18.65%, respectively. This study constructs the model from both subjective and objective aspects, thus providing a reference for urban typhoon risk assessment and prevention.*

Keywords: *Typhoon, Risk assessment, CRITIC, Entropy weighting, TOPSIS*

1. Introduction

China is a country severely hit by typhoons. Typhoon-related heavy rains, landslides and storm surges cause big economic losses and many casualties. So, accurately assessing typhoon risks[1] is key to making good disaster prevention and reduction plans, which can cut losses and save lives.

In the field of typhoon risk assessment, global research focuses on integrated systems like HAZARDS-MU, HAZUS-Wind, and FPHL models. Although China's research on typhoon disasters started later, it has made significant progress in recent years. For example: Liu Yayu[2] developed a rapid typhoon disaster assessment method using Case-Based Reasoning (CBR) technology. Huang Liying[3] conducted a comprehensive typhoon risk assessment in South China using subjective and objective methods, constructing a machine learning-based prediction model. Zhou Na[4] employed fuzzy mathematics combined with BP neural networks to predict typhoon disaster risks. Huang Yonglin[5] established a typhoon disaster risk assessment model integrating geographic detectors, coefficient of variation methods, and spatial weighted overlay analysis. He Yueshuang[6] constructed a universal typhoon disaster chain based on complex network theory and developed a time-series risk assessment model. Pan Jinlan[7] used AHP-TOPSIS optimal combination weighting for typhoon disaster risk assessment.

However, many current frameworks have strong subjective biases, relying much on expert judgment and experience. This subjectivity can hurt the comprehensiveness and objectivity of model parameter setting and weight distribution, affecting the accuracy and reliability of results. To solve this, this study uses a systematic approach based on typhoon disaster system theory, looking at multi-dimensional factors like disaster-causing elements, environmental sensitivity, exposed entity characteristics and the disaster-prone environment.

To overcome subjectivity in traditional weight assignment methods, this study introduces CRITIC[8] and EWM[9] as objective measurement tools. These methods scientifically determine the relative importance of each evaluation index by considering both indicator correlations and data variability, ensuring rational and precise weight allocation. The TOPSIS[10] method is then employed to process and

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analyze specific evaluation index data, enhancing the practicality and validity of the assessment model. Based on this, a comprehensive and objective typhoon risk assessment model is constructed.

To validate the model's practical application, Wenzhou City, Zhejiang Province[11], was selected as an empirical case study. Historical typhoon disaster data were analyzed using the natural breaks method[12], classifying typhoon risks into five levels. This classification visually demonstrates regional differences in typhoon disaster risks and provides a robust scientific basis for local government disaster prevention and mitigation decisions.

2. Materials and Methodology

2.1. Evaluation Procedure

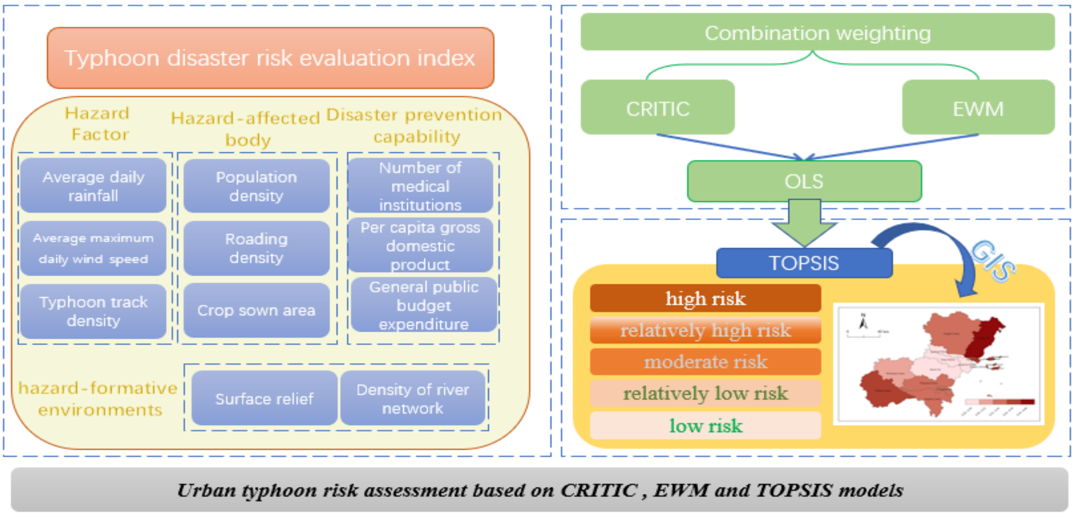

Figure 1 The Risk Assessment Process of Typhoon Disasters

The typhoon disaster risk assessment procedure, as shown in Figure 1, begins with four key aspects: hazard-causing factors, disaster-prone environment, disaster-bearing entities, and disaster prevention capabilities. Eleven indicators, such as average daily rainfall and population density[13], are selected and quantitatively processed. The improved CRITIC and EWM methods determine the influence weights of each indicator on typhoon risk. Based on these weights, the TOPSIS method is used to process the specific indicator data and calculate the risk score. Finally, GIS[14] software visualizes the TOPSIS results, generating the typhoon risk distribution map.

2.2. Data Sources

Wenzhou City, located in southeastern Zhejiang Province, China, covers 12,110 square kilometers of land and 8,649 square kilometers of sea area. Situated between 27°03′N to 28°36′N and 119°37′E to 121°18′E along the southeast coast, Wenzhou lies on a common typhoon path. The city has a subtropical monsoon climate with hot, rainy summers and frequent typhoons. Its complex terrain, including mountains, hills, and plains, intensifies typhoon-induced precipitation. Establishing a scientific assessment system is essential for disaster prevention and urban management in typhoon-prone areas.

This paper develops a first-level indicator system from four dimensions: hazard factors, disaster-prone environment, disaster-bearing bodies, and disaster prevention capabilities. The first two dimensions assess typhoon risk occurrence, while the latter two evaluate the city's vulnerability and response capacity. The typhoon risk formula is defined as follows:

$$T = DP\,\mathrm{AR} \tag{1}$$

Based on previous studies, this article selects the relevant data of Wenzhou City from 2003 to 2023. In view of the fact that Longgang City was officially established by converting from a town to a city on September 25, 2019, the data of Longgang City was not separately listed in the statistical yearbooks of Wenzhou City prior to 2020. To ensure the consistency and integrity of the data, in the analysis of 2020 and thereafter, the data of Longgang City is merged into Cangnan County. The selection of specific indicators and their significance are presented in Table 1.

Table 1 Construction of the Evaluation Index System

First-level evaluation indicators	Second-level evaluation indicators	Significance
Hazard Factor D	Average daily rainfall	The average daily rainfall in a certain area
	Average maximum daily wind speed	The average of the maximum wind speed in a day in a certain area
	Typhon track density	The ratio of the length of the typhoon path to the area of the region
Hazard-affected body P	Surface relief	The height difference between the highest and lowest points within a certain area centered on a certain point
	Density of river network	The ratio of the total length of the main and tributary streams in a basin to the area of the basin
Disaster prevention capability A	Population density	The population density per unit area of a certain region
	Road density	The total length of roads per unit area of a certain region
	Crop sown area	The total area of crops actually sown throughout the year in a certain region.
Disaster prevention capability R	Number of medical institutions	The total number of medical institutions in a certain region
	Per capita gross domestic product	The per capita gross domestic product in a certain region
	General public budget expenditure	The scale of government fiscal expenditure in a certain region

2.3. Determination of Index Weights Based on the CRITIC-EVM Approach[15]

The CRITIC method and EWM are objective weighting approaches offering distinct advantages within the multi-index decision-making framework. CRITIC focuses on both the contrast intensity and conflicts among indicators by quantifying their correlations. In contrast, EWM determines indicator weights based on information entropy, which measures data uncertainty. Lower information entropy indicates more concentrated information and higher discriminatory power, leading to greater weight assignment. EWM objectively reflects each indicator's significance in decision-making by calculating information entropy.

CRITIC compensates for EWM's limitation in analyzing mutual influences among indicators, offering a more comprehensive perspective. Conversely, EWM addresses CRITIC's limitation in assessing the impact of indicator dispersion on weighting by precisely quantifying discriminatory power through information entropy. This paper integrates both methods to construct a combined weighting model based on CRITIC and EWM.

Step 1: Firstly, dimensionless processing is conducted: Supposing there are m evaluation objects and n evaluation indicators, the original data are, $X_{i,j}$, $i=1,\cdots,m$, $j=1,\ldots,n$:

$$\mathrm{x}_{ij}=\frac{X_{\max}-X_{ij}}{X_{\max}-X_{\min}}\ (X_{i,j}\ \text{is a positive indicator}) \tag{2}$$

$$\mathrm{x}_{ij}=\frac{X_{\max}-X_{ij}}{X_{\max}-X_{\min}}\ (X_{i,j}\ \text{is a negative indicator}) \tag{3}$$

Among them, $X_{\max}$ and $X_{\min}$ respectively represent the maximum and minimum values of the jth indicator, x_{ij} and X_{ij} respectively denote the standardized and original values of the jth indicator in the ith year.

Step 2: To calculate the weights by the CRITIC method, the weight formula as follows can be constructed in this paper:

ISSN 2616-5872 Vol. 7, Issue 1: 55-62, DOI: 10.25236/AJEE.2025.070107

$$W_{1j}=\frac{\frac{\sigma_j}{\bar{x}_j}\sum_{i=1}^{m}(1-|\alpha_{ij}|)}{\sum_{j=1}^{k}c_j} \tag{4}$$

Among them, W_{1j} is the weight of the jth indicator, α_{ij} is the correlation coefficient between the ith indicator and the jth indicator, and ρ_j represents the standardized value and the original value of the jth indicator.

Step 3: Based on the calculation of weights by EWM, the following weight formula can be constructed in this paper:

$$p_{ij}=\frac{x_{ij}}{\sum_{i=1}^{Y}x_{ij}} \qquad E_j=-\frac{1}{\ln Y}\sum_{i=1}^{Y}p_{ij}\ln p_{ij} \tag{5}$$

$$W_{2j}=\frac{1-E_j}{K-\sum_{j=1}^{K}E_j} \tag{6}$$

Among them, p_{ij} indicates the occurrence probability of the jth indicator for the ith evaluation object, E_j represents the entropy output of the jth indicator, and W_{2j} denotes the weight of the jth indicator.

Step 4: Least Squares Method[16]:

The least squares method aims to identify the optimal fit between data and model by minimizing the sum of squared errors. This approach, by determining the optimal combined weights, can effectively diminish the weight deviations calculated by the EWM and CRITIC methods. Consequently, in this paper, an objective function is constructed based on the concept of the least squares method, in order to achieve the unification of the combined weights in terms of value quantity and target quantity.

$$\min O(W)=\sum_{i=1}^{n}\sum_{j=1}^{m}\left[\left(W_{1j}-W_j\right)x_{ij}\right]^2+\left[\left(W_{2j}-W_j\right)x_{ij}\right]^2 \tag{7}$$

In the equation, W_j , W_{1j} , and W_{2j} respectively denote the combined weight, the weight obtained by the Entropy Weight Method, and the weight obtained by the CRITIC Method of the jth indicator.

Among them, the constraint conditions are:

$$\sum_{j=1}^{m}W_j=1, W_j\geq 0\left(j=1,2,\ldots,m\right) \tag{8}$$

In this research, the Lagrangian function is introduced, which is constituted by the least squares objective function and the constraint conditions, and is presented as follows:

$$L=\sum_{i=1}^{n}\sum_{j=1}^{m}\left[\left(W_{1j}-W_j\right)x_{ij}\right]^2+\left[\left(W_{2j}-W_j\right)x_{ij}\right]^2+4\lambda\left(\sum_{j=1}^{m}W-1\right) \tag{9}$$

Calculate the partial derivatives concerning each variable in the Lagrangian function:

$$\frac{\partial L}{\partial W_j}=-\sum_{i=1}^{n}2\left(W_{1j}+W_{2j}-2W_j\right)x_{ij}^2+4\lambda=0 \qquad \frac{\partial L}{\partial \lambda}=4\left(\sum_{j=1}^{m}W_j-1\right)=0 \tag{10}$$

Be represented in matrix form:

$$\begin{bmatrix} A & e \\ e^T & 0 \end{bmatrix}\times\begin{bmatrix} W \\ \lambda \end{bmatrix}=\begin{bmatrix} B \\ 1 \end{bmatrix} \tag{11}$$

The resulting combined weight is:

$$W=A^{-1}\left[B+\frac{1-e^TA^{-1}B}{e^TA^{-1}e}e\right] \tag{12}$$

2.4. Comprehensive Evaluation Based on the TOPSIS Method[17]

The TOPSIS method is a comprehensively and extensively applied evaluation approach that is capable of fully extracting and exploiting the original data information and precisely reflecting the disparities among various evaluation plans.

Step 1: Firstly, dimensionless treatment is carried out:

$$Z=\begin{pmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{m1} & \cdots & z_{mn} \end{pmatrix}=Z=\begin{pmatrix} x_{11}*\mathrm{W}_1 & \cdots & x_{1n}*\mathrm{W}_n \\ \vdots & \ddots & \vdots \\ x_{m1}*\mathrm{W}_1 & \cdots & x_{mn}*\mathrm{W}_n \end{pmatrix} \tag{13}$$

Step 2: Positive and negative ideal solutions:

$$Z^{+}=\left(v_1^{+},v_2^{+},\cdots v_n^{+}\right)=\left\{\max v_{ij} \mid j\in J_1,\min v_{ij} \mid j\in J_2\right\} \tag{14}$$

$$Z^{-}=\left(v_1^{-},v_2^{-},\cdots v_n^{-}\right)=\left\{\max v_{ij} \mid j\in J_1,\min v_{ij} \mid j\in J_2\right\} \tag{15}$$

In the equation, J_1 and J_1 denote the sets of positive and negative indicators respectively.

Step 3: Compute the distances of the evaluation object to the positive and negative ideal solutions:

$$Z_i^{+}=\sqrt{\sum_{j=1}^{n}(\mathrm{v}_{ij}-\mathrm{v}_j^{+})^2} \qquad Z_i^{-}=\sqrt{\sum_{j=1}^{n}(\mathrm{v}_{ij}-\mathrm{v}_j^{-})^2} \tag{16}$$

Step 4: Determine the relative closeness coefficient of the i-th evaluation object to the ideal solution:

$$T_i=\frac{Z_i^{-}}{Z_i^{+}+Z_i^{-}} \tag{17}$$

In the equation, $T_i\in[0,1]$, after sorting the values of T_i, the greater the value of T_i, the higher the risk of typhoon exposure for the research object; conversely, the lower.

3. Results

3.1 Composite weight

The specific values of selected secondary indicators for each district in Wenzhou are presented in Figure 2.

Based on formulas (2) to (17), the original data were subjected to dimensionless processing, and the corresponding index weights were calculated. The results are presented in Table 2.

Table 2 Weights of Typhoon Risk Assessment Indicators in Wenzhou City

First-level evaluation indicators	Second-level evaluation indicators	W_{1j}	W_{2j}	W_j
Hazard Factor D	D1	0.0736	0.0286	0.0511
	D2	0.0726	0.0448	0.0587
	D3	0.1071	0.0775	0.0923
Hazard-affected body P	P1	0.1031	0.0485	0.0758
	P2	0.0583	0.4758	0.2671
Disaster prevention capability A	A1	0.0734	0.0684	0.0709
	A2	0.0758	0.0637	0.0697
	A3	0.1407	0.0580	0.0993
Disaster prevention capability R	R1	0.1041	0.0593	0.0817
	R2	0.0874	0.0295	0.0584
	R3	0.1039	0.0459	0.0749

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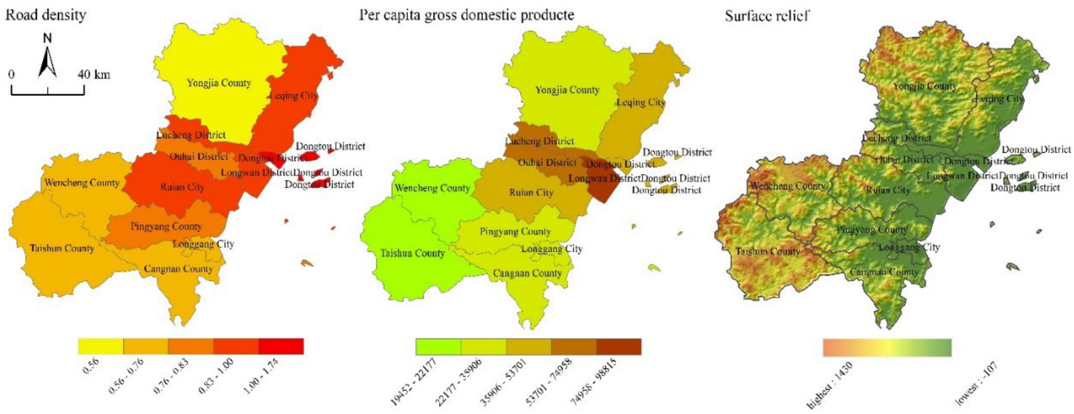

Figure 2 The specific numerical values of secondary indicators

3.2 Comprehensive Assessment Based on the TOPSIS Method

The TOPSIS approach was employed to rate each region. To render the data more intuitive and comprehensible, the Jenks natural breaks method was utilized in this paper to categorize Ti into five risk grades: I (high risk), II (relatively high risk), III (moderate risk), IV (relatively low risk), and V (low risk). The score ranges for each level are detailed in Table 3.

Table 3 Risk grades and the corresponding scoring intervals

Risk grade	Scoring interval	District
I (high risk)	[0.29,0.30]	Taishun County, Yueqing City
II (relatively high risk)	[0.30,0.32]	Dongtou District
III (moderate risk)	[0.32,0.36]	Pingyang County, Longgang City, Cangnan County, Yongjia County
IV (relatively low risk)	[0.36,0.39]	Wencheng County
V (low risk)	[0.39,0.60]	Ruian City, Longwan District, Ouhai District, Lucheng District

As shown in Figure 3, Taishun County and Yongjia County in Wenzhou City are classified as Level I (high risk), indicating the most significant typhoon impact. Dongtou District is rated Level II (relatively high risk). In contrast, Lucheng District, Ouhai District, Longwan District, and Ruian City have lower risks and are less affected. Therefore, special attention should be given to typhoon prevention in Taishun County, Yongjia County, and Dongtou District, with timely implementation of emergency response and rescue measures to ensure effective disaster mitigation.

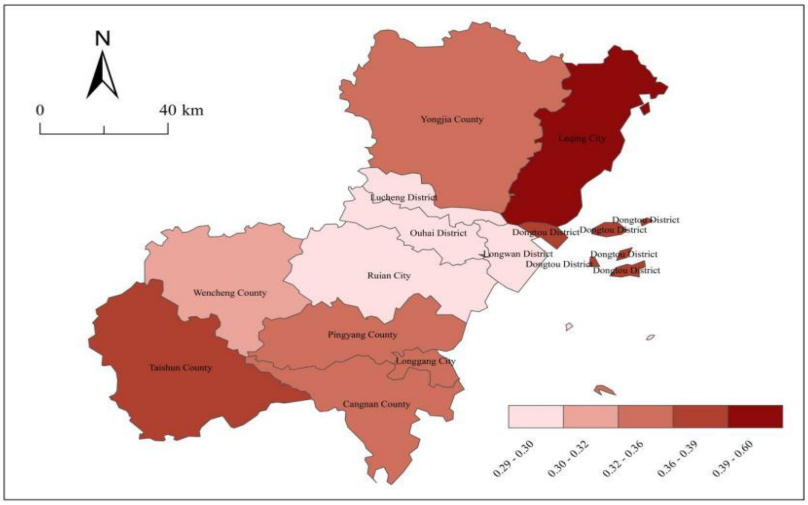

Figure 3 The results of risk classification in the study area

The terrain of Taishun County slopes from northwest to southeast, featuring numerous mountains and high average daily rainfall. Before a typhoon, detailed personnel transfer and resettlement plans should be formulated for high-risk areas such as mountain torrents and geological hazards. This ensures timely information dissemination, availability of rescue materials, and protection of lives. Yueqing City also slopes from northwest to southeast and has a high average maximum daily wind speed. Over the past decade, its crop-sown area has ranked among the top in Wenzhou City. Before a typhoon, protective measures should be taken for farmlands, including reinforcing fences and dredging drainage ditches. Buildings with potential safety hazards should be evaluated and reinforced or demolished as necessary. Dongtou District has low-lying terrain adjacent to the sea and one of the highest population densities in Wenzhou City. Before a typhoon, inspections, and maintenance of sea dykes should be enhanced to ensure structural integrity and prevent seawater backflow and wave impact. Detailed personnel transfer plans should also be formulated, clearly defining routes, methods, and resettlement locations to ensure rapid and orderly evacuation during the typhoon period.

4. Discussions

This study is predicated on a multi-dimensional dataset of Wenzhou City, Zhejiang Province, to surmount the subjectivity and constraints of the single weighting method in previous urban typhoon risk evaluations. Through the integration of EWM and CRITIC, in conjunction with the TOPSIS evaluation model, a more objective and ubiquitous typhoon risk assessment system has been established. This system holds the potential to furnish new tools and approaches for typhoon risk assessment and management in various urban regions. Nevertheless, the data of this study is confined to Wenzhou City, and only the common indicators of the typhoon-impacted areas are taken into account, without differentiating the disparities between inland and coastal areas. Future research is required to delve deeper into key indicators such as sea surface temperature and the distance between typhoons and coastlines, to comprehensively optimize the scientific basis for typhoon risk assessment.

5. Conclusions and recommendations

Typhoons significantly impact regional socio-economic systems, necessitating accurate risk assessment and enhanced disaster prevention. This study focuses on Wenzhou City, Zhejiang Province, China, developing a comprehensive typhoon risk assessment framework based on two decades of data. The framework includes four core elements: disaster-inducing factors, predisposing environments, disaster-bearing bodies, and prevention capabilities, refined into eleven secondary indicators. Weight assignment integrates EWM and CRITIC methods for scientific accuracy, while TOPSIS establishes the risk assessment model. GIS natural break classification categorizes Wenzhou into five risk grades, identifying Yueqing City and Taishun County as high-risk areas. Recommendations include:

(1) Optimize local government emergency response plans by developing detailed typhoon emergency protocols to ensure prompt and efficient actions. These plans should encompass early warning systems, emergency procedures, resident evacuation and resettlement, and rescue operations.

(2) Strengthen typhoon monitoring and early warning capabilities through continuous upgrades to monitoring networks, improvements in forecast accuracy and timeliness, and the dissemination of warnings via various media channels.

(3) Enhance urban infrastructure resilience by reinforcing key structures such as buildings, road networks, and bridges, and intensifying routine maintenance to minimize potential typhoon impacts.

Acknowledgement

Author contributions Wenli Chen, Yushan Huang, and Bi Xiong contributed equally to all aspects of this work; Guorui Zhao gave some useful suggestions to the work. All authors reviewed the manuscript.

Funding This research was supported by the Discipline Co-construction Project of the Guangdong Province Philosophy and Social Sciences "Thirteenth Five-Year Plan": Research on the Precise Identification and Early Warning of Academically Challenged Students in Universities Based on Machine Learning Algorithms(GD20XJY20), The 2024 Research Project of the Guangdong Provincial Undergraduate Mathematics Teaching Guidance Committee for Higher Education Institutions.

ISSN 2616-5872 Vol. 7, Issue 1: 55-62, DOI: 10.25236/AJEE.2025.070107

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