Analysis on the Reliability of Coastal City Transportation from the Perspective of Resilience: A Case Study of Yantai City, Shandong Province, China

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Abstract: As the global climate continues to change and environmental damage has intensified, it has seriously affected the safety and sustainable development of coastal cities. Improving the resilience of coastal cities has become their strategic consensus to respond to changes. Based on the theory of resilient cities, using complex network analysis methods and taking reliability analysis as the starting point, a coastal road resilience evaluation system was constructed, and the impact analysis and resilience evaluation were carried out using Yantai City as an example. The results show that: 1) Yantai municipal road network (national and provincial road) has high reliability and strong robustness; 2) the network has important road sections with greater influence. Based on this, this article proposes strategies for improving urban resilience.

1. Introduction
Nowadays, most coastal cities mainly focus on "defense" for disaster prevention and control, but it ignores the uncertainty of external changes and the outdated assumption that infrastructure can remain unchanged. The concept of resilient city is different from this one, which emphasizes not only the defense during the disaster, but also the judgment ability before the disaster, that is, the ability to distinguish and resist the external impact. Therefore, this paper tries to explore the "discrimination-adapt-defense" resilient city planning method from the perspective of traffic network reliability.

The research on transportation network mainly focuses on the following issues: the determination of transportation network Hub points, the determination of transportation capacity allocation based on the shortest path choice, the congestion of transportation network, and the destruction resistance and attack protection of transportation network. According to the content of this paper, we mainly focus on the study of the damage resistance (more commonly known as reliability) of the transportation network. The reliability study of highway network system began in the 1980s and has been widely used in traffic operation management and disaster relief planning. Road network reliability is the ability to complete the predetermined functions under the specified service level and specified conditions [3]. There are many random factors that lead to the unreliable road network. For example, daily road congestion and daily traffic demand are called repeatability factors, while natural disasters and occasional traffic accidents are called unrepeatability factors. At present, the research on road network reliability at home and abroad mainly focuses on three aspects: the research on road network connectivity, the research on travel time reliability, and the research on capacity reliability [4, 5]. However, there are few researches...
on the traffic network within the coastal area, and most of the researches are theoretical ones, while the empirical ones based on reliability analysis are scarce.

Coastal regional highways are the basic conditions for ensuring people's production and life, and are the leading and basic facilities for regional development. From the perspective of resilience, this paper uses complex theory to study the reliability of Yantai's urban road network (national and provincial roads), in order to evaluate its reliability characteristics and provide a basis for resilient city planning.

2. Research methods

Focus on exploring the theory of toughness "discriminant - adaptation - defense" planning method, therefore the static and dynamic reliability of regional highway network reliability research, designed to draw the network clustering and more key sections, so as to achieve the purpose of the pre-disaster prevention, which can be in the event of a disaster before you can judge which area need to fortify. Therefore, the aggregation coefficient and degree distribution index are selected for the study of static reliability. In the dynamic reliability level, the maximum connected subgraph size index is selected to measure the integrity of the network, and the whole network connectivity efficiency index is selected to measure the network efficiency after the network is disturbed (as shown in Figure 1).

![Figure 1 Overall research idea](image1.png)

Select the real system (as shown in Figure 2), and according to the semantics constructed by the network model, this level studies the numbering of the roads between adjacent intersections (that is, the edges of the roads are numbered, and the edges of the roads in the complex network As the network node, Because this paper is a regional study and the research focus is on the regional level, only national and provincial roads are taken as the research objects, and rural roads are not included.) A complex network model is established, as shown in Figure 2.

![Figure 2 Traffic plan and network topology diagram of Yantai City, Shandong Province, China](image2.png)
3. Analysis of calculation results

3.1 Degree distribution

Degree distribution $P(k)$ indicates the proportion of nodes with a degree value of $k$ to the total number of network nodes in the network. Cumulative degree distribution $P_k$ represents the proportion of nodes whose degree value is not less than $k$ to the total number of network nodes, that is, the probability that a node whose degree value is not less than $k$ is randomly selected in the network. The calculation formula is:

$$P_k = \sum_{i=k}^{\infty} P(k')$$

(1)

The node degree distribution and cumulative degree distribution are calculated, as shown in Figure 3.

It can be seen from the figure that from the perspective of degree distribution, the nodes with degree values of 3 and above in the Yantai municipal road network exceed 85%, and nodes with degree values of 1 and 2 account for 3.7% and 8.2%, respectively. This shows that most road segments are at least There are 3 road sections connected to it, many road sections have a large number of connections, and the node degree values are only 1, 2, 3, 4, and 6, which have obvious non-scale characteristics as a whole. Third, the average degree of the railway physical network is 3.886, and the degree value is relatively reasonable. Once an emergency or sabotage occurs on the network, it will not lead to a rapid decrease in network operation efficiency.

![Node degree distribution diagram of urban highway network](image)

3.2 Clustering coefficient

The clustering coefficient is used to describe the aggregation of nodes in the local network. Assuming that node $i$ in the network is connected to other $k_i$ nodes, the ratio of the actual number of edges $e_i$ between adjacent $k_i$ nodes to the maximum number of edges that may exist, is defined as The clustering coefficient of node $C_i$ specifies that when the node degree is 1, the clustering coefficient is 0. The calculation formula for the aggregation coefficient $C_i$ of node $i$ is:

$$C_i = \frac{2E_i}{k_i(k_i-1)}$$

(2)

The clustering coefficient is used to reflect the tightness of the local structure in the network. The higher the clustering coefficient of a node, the tighter the local network structure centered on the node.

In the highway network, the aggregation coefficient reflects the local aggregation of the traffic network, and the distribution of the node aggregation coefficient is obtained through calculation (as shown in Figure 4).

As can be seen from the figure, from the distribution of the aggregation coefficient, there are 19 sections with an aggregation coefficient of 1 in the network, accounting for 12.03% of the total; 9 sections with an aggregation coefficient of 0, accounting for 5.7% of the total, and the aggregation coefficient of the physical railway network is 0.391 (the value range is 0~1), the higher the value, it can be concluded that the urban transportation network of Yantai has better aggregation, basically showing a grid-like road network.
3.3 The largest connected subgraph

The maximum connectivity subgraph is used to measure the overall network connectivity. The larger the value, the stronger the network connectivity. When a node is deleted from the network, the overall network connectivity will weaken or even disappear, which means that such nodes determine the overall connectivity of the network. The reliability of such nodes should be strengthened to increase the overall reliability of the system.

The calculation formula for the largest connected subgraph is:

\[ S = \frac{N'}{N} \]

In formula (3), \( N' \) represents the number of nodes in the largest connected subgraph after the network is attacked, and \( N \) represents the number of nodes in the network when it is not attacked. As the nodes in the network are attacked, the largest connected subgraph in the network may become smaller, reflecting the changes in the network topology before and after the network is destroyed.

The calculation shows that the initial maximum connected subgraph of the highway network is 158. When the single-point interference strategy is adopted, it can be seen that the maximum connected subgraph of the urban highway network in Yantai City has basically no change (as shown in Figure 5), and only a few critical road section nodes will only cause a slight drop when they are interfered (as shown in Table 1).
3.4 Entire network connection efficiency

The global connectivity efficiency \( H_{ab} \) refers to the sum of the connectivity efficiency between all pairs of nodes in the network, and the calculation formula is:

\[
H_{ab} = \sum_{i \neq j} \frac{1}{d_{ij}}
\]  

(4)

In formula (4), \( d_{ij} \) represents the shortest path length between nodes.

The initial connection efficiency of the road network is 0.1816. When the single-point interference strategy is adopted, it can be seen that when a section of the road is damaged, the overall network connection efficiency of the road network in Yantai City will change to varying degrees according to the location of the road section (as shown in the figure) 6). At the same time, after some key road sections are destroyed, it will have a greater impact on the efficiency of the entire network. Based on this, the key road sections can be identified and divided (as shown in Table 2).

| Damaged individual section number | The efficiency of the whole network |
|----------------------------------|-----------------------------------|
| 28                              | 0.176281                          |
| 129                             | 0.176156                          |
| 44                              | 0.175906                          |
| 71                              | 0.1758                            |
| 72                              | 0.175157                          |
| 101                             | 0.174992                          |
| 47                              | 0.174733                          |
| 51                              | 0.17451                           |
| 132                             | 0.171492                          |
| 149                             | 0.16528                           |

4. Conclusion

① Yantai city road network (national highway, provincial highway) has high reliability and strong robustness
The study found that Yantai's municipal road network is relatively complete, well constructed, and has strong robustness. Under the single-point interference strategy, the maximum connectivity subgraph and the overall network connectivity efficiency of this network are almost unchanged, showing high connectivity and strong information transmission capabilities.

②There are important road sections with greater influence on the network

Through the dynamic reliability analysis of the network, some important road sections that have a greater impact on the network reliability are identified, and the road sections need to be classified into important levels.

Therefore, the research methods mentioned in this article can meet the requirements of “discrimination-adaptation-defense” for resilient cities, thereby enhancing urban resilience, such as optimizing disaster prevention space and emergency evacuation systems based on identified key road sections, and strengthening disaster management resilience thinking; guide urban population development based on robust characteristics, build a framework for land resilience planning, and accelerate the construction of compact cities.

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