Risk Assessment on Beijing Urban Infrastructure Vulnerability

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Abstract. In this paper, a comprehensive evaluation indicator system of urban infrastructure was constructed, and a vulnerability assessment model of urban infrastructure based on AHP method was developed. Taking Beijing as an example, an empirical research based on the date of Beijing urban infrastructure in 2008 was conducted. The research in this paper is a useful exploration on vulnerability assessment, which can provide the foundation and support for government's decision-making on urban disaster prevention and mitigation.

Introduction

The infrastructures of city involves water supply and drainage，road and public traffic，heat and gas supply，post and telecommunications and so on. The infrastructures of city are the important factors for the running and development of the city. They are also the basements and carriers of the flow logistics, information flow of the city.

Generally, The city infrastructures in China are the basic facilities for people's living and production. They are technology oriented facilities. In this paper, the city infrastructures include four sub-systems which are water supply and drainage system, transportation system, energy supply system and post and telecommunications system. It's a the narrow and the normal definition of city infrastructures.

In this paper, a comprehensive evaluation indicator system of urban infrastructure was constructed, and a vulnerability assessment model of urban infrastructure based on AHP method was developed. Taking Beijing as an example, an empirical research based on the date of Beijing urban infrastructure in 2008 was conducted. The research in this paper is a useful exploration on vulnerability assessment, which can provide the foundation and support for government's decision-making on urban disaster prevention and mitigation.

The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is due to Saaty (1980) and is often referred to, eponymously, as the Saaty method. It is popular and widely used, especially in military analysis, though it is not, by any stretch of the imagination, restricted to military problems. its essence is to construct a matrix expressing the relative values of a set ofattributes. For example, what is the relative importance to the management of this firm of the cost of equipment as opposed to its ease of operation? They are asked to choose whether cost is very much more important, rather more important, as important, and soon down to very much less important, than operability. Each of these judgments is assigned a number on a scale.

The procedure for using the AHP can be summarized as:

（i）Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives；

（ii）Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements. For example, when comparing potential real-estate purchases, the investors might say they prefer location over price and price over timing；

（iii）Synthesize these judgments to yield a set of overall priorities for the hierarchy. This would combine the investors' judgments about location, price and timing for properties overall priorities for each property；

judgment matrix A ：

$$A = \begin{pmatrix} a_{11} & K & a_{1n} \\ M & 0 & M \\ a_{n1} & L & a_{nn} \end{pmatrix}_{n \times n}$$

among， a_{ij} is the degree of importance of index i compared the index j， 1~9and their reciprocal are used as the scale， and $a_{ij} = \dfrac{1}{a_{ji}}$; $a_{ii} = 1$.

（iv）Check the consistency of the judgments；

$$M_i = (\prod_{j=1}^{n} a_{ij})^{\frac{1}{n}}, (i = 1, 2, \cdots, n) \qquad (1)$$

$$w_i = \frac{M_i}{\sum_{j=1}^{n} M_j}, (i = 1, 2, \cdots, n) \qquad (2)$$

Eigen value of maximum： $\lambda_{\max} = \dfrac{1}{n} \sum_{i=1}^{n} (\dfrac{(Aw)_i}{w_i})$ ， among, $(Aw)_i$ is Aw's i th component。 When $\lambda_{\max}$ Satisfy certain requirements and through the consistency check， weight matrix isobtained： $W = [w_1, w_2, \cdots, w_n]^T$ 。

（v）Come to a final decision based on the results of this process.

Assumed the weight matrix of the （$k-1$）th level 's n_{k-1} factors compared the objective：

$$w^{(k-1)} = \left[w_1^{(k-1)}, w_2^{(k-1)}, \cdots, w_n^{(k-1)} \right]^T \qquad (3)$$

Assumed a single criterion sort weight vector of the k th level 's n_k factors compared the ($k-1$)th's j factors $(j = 1, 2, \cdots, n_{k-1})$ ：

$$u_j^k = (u_{1j}^{(k)}, u_{2j}^{(k)}, \cdots, u_{n_k j}^{(k)})^T, j = 1, 2, \cdots, n_{k-1} \qquad (4)$$

A $n_k \times n_{k-1}$ matrix can be obtained ：

$$U^{(k)} = \begin{bmatrix} u_{11}^k & u_{12}^k & \cdots & u_{1n_{k-1}}^k \\ u_{21}^k & u_{22}^k & \cdots & u_{2n_{k-1}}^k \\ M & M & 0 & M \\ u_{11}^k & u_{11}^k & \cdots & u_{n_k n_{k-1}}^k \end{bmatrix} \qquad (5)$$

Finally ， decision can be conclude based on the results of this process.

Index System Construction

Forty-six basic index which were used to monitor the system of the Beijing's infrastructures were summarized. There must be a relationship of correlation between the indexes, because AHP method was used to make the evaluation. Based on the review of related literatures and previous related research, a two level index system was built by screening key indicators. The index system concludes goal layer, criterion layer and alternative layer. The goal layer is the infrastructure level in Beijing。Criterion layer conclude the index of water supply and drainage system, transportation system, energy supply system and post and telecommunications system. The alternative layer concludes fifty basic key indexes which were shown by the table 1.

1.Water Supply And Drainage System

①Ability of water supply：Reflect the capacity of water supply of the city's waterworks system. The data can be acquainted from Beijing water group.

②City daily water supply：reflect the capacity of water supply for the center districts of the city.

③Sewage process：Capacity of the actual sewage treatment of the city.

Table1 The index system of the infrastructure in Beijing

Goal layer	Criterion layer	Alternative layer
City Infrastructures of Beijing	Water Supply And Drainage (WSD)	Ability of water supply
		City daily water suppl
		Sewage process
	Transportation (T)	Daily average passengers carrying capacity
		Average number of passengers by public transportation
		Average number of passengers by rapid transit
		Quantity of good transported
	Energy supply (ES)	Capacity of electric power supply
		Capacity of gas supply
		Capacity of heat supply
	Post and telecommunic—ations (PT)	Telecommunication trade amount
		Local telephone subscribers
		Cellular mobile telephone subscribers
		Customers of internet
		Postal business income

Table1 The index system of the infrastructure in Beijing

2.Transportation system

①Daily average passengers carrying capacity: Total average transport passengers by the traffic system。

②Average number of passengers by public transportation :Total average transport passengers by bus .

③Average number of passengers by rapid transit：Total average transport passengers by bus.

④Quantity of good transported：total quantity of daily business goods.

3.Energy supply

①Capacity of electric power supply：Total electric power supply by the power system of the city.

②Capacity of gas supply：Total gas supply for the citizens and industries，including loss and outsourcing.

③Capacity of heat supply：Total heat supply by the heat supply system of the city。

4.Post and telecommunications system

① Telecommunication trade amount ： All the telecom business and value-added telecommunication business.

②Local telephone subscribers：Total number of fixed-line phone customers in the city.

③Cellular mobile telephone subscribers：Total number of mobile phone customers in the city.

④customers of internet：Total number of internet customers in the city.

⑤Postal business income：total volume of all kinds of postal business.

All the indexes should be made a dimensionless treatment before statistic the date.

For the positive index：

$$X' = (X-Xmin) / (Xmax-Xmin) \qquad (6)$$

For the inverse index：

$$X' = (Xmax-X) / (Xmax-Xmin) \qquad (7)$$

According to the relevant information，the judgment matrix of Beijing's infrastructures can be determined：

Table2 the weight of the indexes of the infrastructure system

Goal layer	weight	Criterion Layer	Weight	Alternative layer	Weight
City Infrastructures of Beijing	1	Water Supply And Drainage	0.2680	Water supply	0.1007
				Water using	0.6738
				sewage treatment	0.2255
		Transportation	0.4859	Total traffic	0.1026
				bus	0.5076
				rapid transit	0.3243
				good transported	0.0655
		Energy supply	0.0477	Electric Supply	0.6267
				Gas supply	0.2797
				Heat supply	0.0936
		Post and telecommunications	0.1984	Total	0.1830
				Fixed-phone	0.0837
				Mobile-phone	0.0465
				Internet	0.2900
				Income	0.3968

The level of the infrastructure can be divided into five grades：：

Table3 Evaluation standard of the infrastructure

Grade	I	II	III	IV	V
Interval	0-0.2	0.2-0.4	0.4-0.6	0.6-0.8	0.8-1.0

Grade V means the level of the infrastructure is very good；grade IV means good. Grade III means normal；grade IV means not good, and grade V means the worst.

Application

According the data of the four sub-systems in 2008, the scores of each index of the systems can be obtained:

Table 4the scores of the infrastructure index

Level I	Level II	Alternative layer	Score
City Infrastructures of Beijing	Water Supply And Drainage	Water supply	0.814
		Water using	0.784
		sewage treatment	1.000
	Transportation	Total traffic	0.043
		bus	0.785
		rapid transit	0.604
		good transported	1.000
	Energy supply	Electric Supply	0.812
		Gas supply	0.491
		Heat supply	1.000
	Post and telecommunications	Total	1.000
		Fixed-phone	0.518
		Mobile-phone	0.378
		Internet	0.875
		Income	0.923

The scores and the weights of level 2 indexes were obtained:

Table5 the scores and the weights of the level 2 indexes

Criterion layer	weight	score	Alternative layer	weight	score
Water Supply And Drainage	0.2680	0.840	Water supply	0.1007	0.814
			Water using	0.6738	0.784
			sewage treatment	0.2255	1.000
Transp Ortation	0.4859	0.660	Total traffic	0.1026	0.043
			bus	0.5076	0.785
			rapid transit	0.3243	0.604
			good transported	0.0655	1.000
Energy	0.0477	0.740	Electric Supply	0.6267	0.812
			Gas supply	0.2797	0.491
			Heat supply	0.0936	1.000
Post and telecomm unications	0.1984	0.860	Total	0.1830	1.000
			Fixed-phone	0.0837	0.518
			Mobile-phone	0.0465	0.378
			Internet	0.2900	0.875
			Income	0.3968	0.923

The final scores of the infrastructure system in 2008 was 0.752，between 0.6and 0.8，belong to grade IV，that's to say the level of Beijing' infrastructure is good and has a strong ability of risk resistance.

Conclusion

Research about the vulnerability became a focus issue that the government and scholars concerned. International and domestic academics have different definitions to the vulnerability. Research about the vulnerability of urban infrastructure in China started late, so the theoretical foundation is weak, and the assessment method is relatively simple. Taking Beijing as an example, this paper categorizes urban infrastructure; establish a more systematic and comprehensive urban infrastructure evaluation

index system, and proposed urban vulnerability evaluation model based on AHP method. Some useful study is done on city vulnerability assessments through this paper. And this paper also provides reference and basis for the relevant government departments to determine the key areas and key protection of urban disaster prevention and mitigation.

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