ASSESSMENT OF EMERGENCY BRIDGE DESIGN ALTERNATIVES BY USING ANALYTIC NETWORK PROCESS

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ABSTRACT

The article presents the basic process that uses analytic network process (ANP) to assess emergency bridge design alternatives. ANP is an effective method for the assessment of bridge design alternatives and is widely used in decision making with dependence and feedback. ANP considers all factors, estimates the relative influence from the factors, values factors with ratio ranging from 1 to 9, makes pairwise comparisons on factors, and synthesizes to obtain overall results. An ANP case is conveniently computed by the super decisions ANP software. The case in this study shows how it works. Results of the research provide valuable information and knowledge for Engineers of assessing bridge design alternatives.

Keywords: analytic network process (ANP), decision making, emergency bridge, alternatives assessment

1. Introduction

Due to the considerable infrastructure development, a vast number of bridges have been and are being built in China. The length of those bridges greatly increasing as well. To ensure rapidness in bridge building and the quality of bridges, the most important task before a bridge is built is to use prefabricated technology to speed bridge construction, improve safety, and minimize traffic disruptions. For example, Figure 1 shows temporary bridges for speeding bridge construction (Zhu Yongzhuo, 2004). To ensure the safety of the temporary bridge during construction and to reduce the cost of production, the administrator of the bridge construction often considers the emergency bridge as the construction convenience bridge and organizes the bridge experts to make a comprehensive assessment of the alternative bridge designs of the emergency bridge (Huang Shaojin, 2004; Sun Hongcai, 2001). The overall performance of the

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emergency bridge depends on resolving a multi-objective and semi-structured problem. There is relative dependence between the characteristic index such as safety and cost. For example, if the cost is lower, then the safety aspect of the bridge is reduced. If the safety is higher, then the cost effectiveness is reduced. To find the ultimate solution, this article applies the analytic network process (ANP) (Thomas L. Saaty,2001; Wang Lianfen, Xu Shubai, 1990) that is based on the analytics of factor dependence and feedback to evaluate the alternative bridge designs of the emergency bridge. American Professor Thomas L. Saaty developed a decision science method—analytic network process, which can suit to solve a comprehensive problem like this well. Specifically, this method considers the relative influence and the feedback from the factors, values the factors with ratio scales from 1 to 9(Xu Shubai,1988), makes pairwise comparisons on factors, and synthesizes to obtain overall results.



2. Bridge Design Alternatives

Characteristics such as construction periods, the total length of the bridge, the load-carrying, the width of roadway, the central separated zone of roadway and the navigational headroom below the bridge are given. These characteristics need to be compared as shown below:

1. Safety. As with a new construction project, safety is of primary importance. We will give safety has the highest priority. Safety includes structure strength (S_1), stiffness (S_2) and stability (S_3). A high structure strength temporary bridge must have high stiffness but not necessarily high stability. A high stability temporary bridge however, must have high strength and high stiffness. A high stiffness one can also guarantee the high strength and high stability of temporary bridge.

2. Economy. Economy is determined by the cost of material (E_1), cost of manufacture(E_2), cost of installation(E_3) and cost of maintenance(E_4) in the field. It's incompatible between economy and safety. Higher is the economy index, lower is the safety. Vice versa. And we assume that if higher quality of bridge material is used, then maintenance cost can be reduced.

3. Durability. Durability is the service life expectancy (D_1) of bridges. Determined by the quality of the materials used, durability is a very important measure. For example, steel is durable and relatively easy to construct. On the other hand, the durability of emergency bridge must be relative to construction periods. We also assume that factors such as durability, economy and safety are independent from each other. If the temporary bridge lasts longer than required by the construction period of the final bridge, then safety is assured but results in higher cost. If the durability of the temporary bridge is shorter than the construction period, then safety can not be assured but economy will be higher.

4. Manufacturability. It includes manufacture technology (M_1) in the factory and construction speed (M_2) in the field. High manufacturability shows a good combination of both. Dowel or bolt connection is used in local fixing to guarantee the whole quality of bridge, and welding should be avoided. Because local welding quality is greatly influenced by external factors, the number of local weldings should be minimized.

Economy and safety are interdependent factors. For example, if the construction periods were 3 years but the safety needed to be guaranteed for 5 years, it would mean high material cost, high constructability and lower economy. If the safety only needed to be guaranteed for 3 years, then the material cost and constructability request would be lower, but the safety would be reduced too.

3.Steps of Applying ANP to Evaluating Bridge Design Alternatives

3.1 Building ANP Decision Bridge Model

For a long time when we evaluate the design alternatives of emergency bridges, most of the designs put more attention on the cost of the structure material, but less on construction period. Time means money and profit. Reduce bridge constructing period may complete the construction of bridge ahead of schedule. Sooner the bridge is built, sooner it can produce economic benefit and social benefit. By analyzing the relations among those factors discussed above, we build an ANP decision model which has the dependence relation inside, shown as Figure 2.

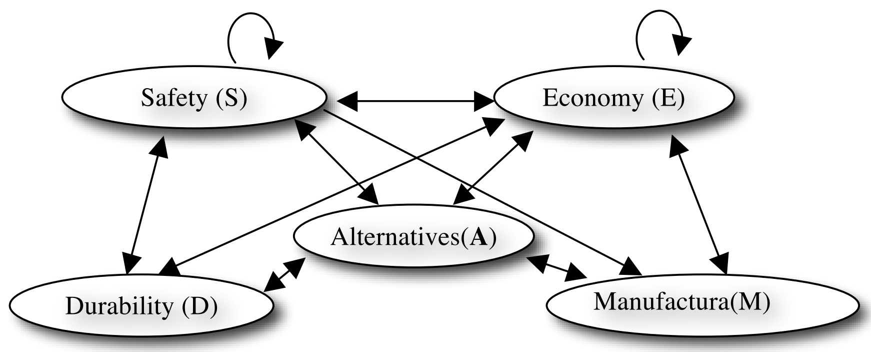

Figure 2. Dependencies for the bridge model

3.2 Computing Weight

In most case, the construction company provides 1 to 3 design alternatives of the emergency bridge for the owner and supervisor to make a decision. If there is only one alternative, ANP is not necessary. In that case, it only needs decision makers to vote. If there are two alternatives, we take vote or AHP method can be used to solve the problem. While there are three or alternatives, the decision making becomes complex. But since the factors have complex dependence and feedback relations, AHP is not suitable to solve the problem. In this paper we take ANP to evaluate a complex decision making process involving 3 design alternatives of the emergency bridge given targeted safety level (Bridge1, Bridge2, Bridge3). We explain how to apply ANP through an example of the design of a temporary bridge in Hangzhou Bay Bridge construction. Bridges 1 is emergency bridge equipment (all prefabricated), Bridge 2 is partly emergency bridge equipment (main beam), which is partly constructed in field; and Bridge 3 is constructed in field.

The importance of the factors that influence the bridge integration process is different. Therefore we use a score ranking from 1 to 9 to ascertain its weight. For the first time we make pair wise comparisons to form the norm-reverse matrix and ascertain the weight for the three alternative designs in all factors as shown in from Table 1 to Table 27. All the calculation process is finished by Super Decisions software. The software takes Windows interface (as shown in Figure 3), and the implementation is simple. We firstly form the ANP model as the same to Figure 2, then we input the score according to the request, then the calculation can be finished in a short period of time.

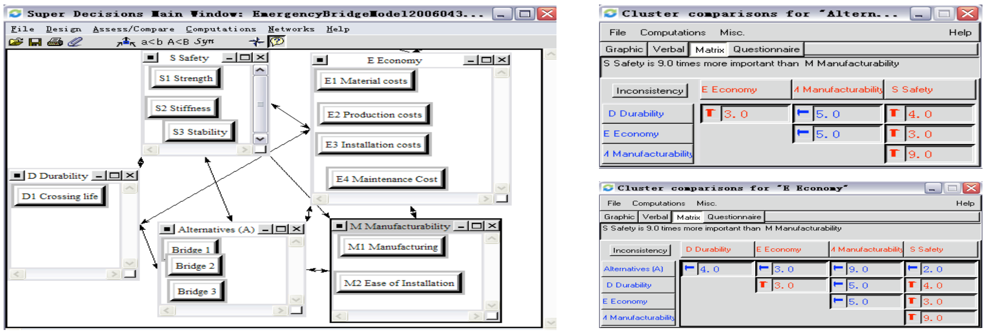

Figure 3. Interfaces of Super Decisions

Table 1 Cluster comparisons for "Alternative"

Alternative	D	E	M	S	W
D	1	1/3	5	1/4	0.141
E	3	1	5	1/3	0.262
M	1/5	1/5	1	1/9	0.045
S	4	3	9	1	0.552

C.R. = 0.066

Table 2 Cluster comparisons for "Durability"

Durability	A	E	S	W
A	1	3	2	0.528
E	1/3	1	1/3	0.140
S	1/2	3	1	0.332

C.R. = 0.052

Table 3 Cluster comparisons for "Economy"

Economy	A	D	E	M	S	W
A	1	4	3	9	2	0.410
D	1/4	1	1/3	5	1/4	0.091
E	1/3	3	1	5	1/3	0.157
M	1/9	1/5	1/5	1	1/9	0.031
S	1/2	4	3	9	1	0.311

C.R. = 0.053

Table 4 Cluster comparisons for "Manufacturability"

Manufacturability	A	E	W
A	1	5	0.750
E	1/5	1	0.250

C.R. = 0.000

Table 5 Cluster comparisons for "Safety"

Safety	A	D	E	M	S	W
A	1	3	6	9	3	0.484
D	1/3	1	1/3	5	1/2	0.107
E	1/6	3	1	5	1/3	0.141
M	1/9	1/5	1/5	1	1/9	0.029
S	1/3	2	3	9	1	0.239

C.R. = 0.098

Table 6 Comparisons to "Bridge 1" node in "Economy"

Bridge 1	E_1	E_2	E_3	E_4	W
E_1	1	3	9	6	0.608
E_2	1/3	1	3	4	0.231
E_3	1/9	1/3	1	3	0.101
E_4	1/6	1/4	1/3	1	0. 060

C.R. = 0.082

Table 7 Comparisons to "Bridge 1" node in "Manufactur"

Bridge 1	M_1	M_2	W
M_1	1	8	0.889
M_2	1/8	1	0.111

C.R. = 0.000

Table 8 Comparisons to "Bridge 1" node in "Safety"

Bridge 1	S_1	S_2	S_3	W
S_1	1	3	2	0.548
S_2	1/3	1	0.8	0.194
S_3	1/2	1.25	1	0.258

C.R. = 0.004

Table 9 Comparisons to “Bridge 2” node in “Economy”

Bridge 2	E_1	E_2	E_3	E_4	W
E_1	1	4	6	3	0.599
E_2	1/4	1	2	3	0.204
E_3	1/6	1/2	1	2	0.108
E_4	1/3	1/3	1/2	1	0.089

C.R. = 0.097

Table10 Comparisons to “D_1” node in “Economy”

D_1	E_1	E_2	E_3	E_4	W
E_1	1	2	5	8	0.494
E_2	1/2	1	8	6	0.376
E_3	1/5	1/8	1	2	0.079
E_4	1/8	1/6	1/2	1	0.052

C.R. = 0.061

Table 11 Comparisons to “Bridge 2” node in “Safety”

Bridge 2	S_1	S_2	S_3	W
S_1	1	1.5	1.2	0.393
S_2	2/3	1	1/2	0.224
S_3	1/1.2	2	1	0.383

C.R. = 0.024

Table 12 Comparisons with respect to D_1 node in “Safety”

D_1	S_1	S_2	S_3	W
S_1	1	5	3	0.637
S_2	1/5	1	1/3	0.105
S_3	1/3	3	1	0.258

C.R. = 0.037

Table 13 Comparisons to “Bridge 2” node in “Manufacture”

Bridge 2	M_1	M_2	W
M_1	1	6	0.857
M_2	1/6	1	0.143

C.R. = 0.000

Table 14 Comparisons to S_3 node in "Safety" cluster

S_3	S_1	S_2	W
S_1	1	2	0.637
S_2	1/2	1	0.105

C.R. = 0.000

Table15 Comparisons to "Bridge 3" node in "Economy"

Bridge 3	E_1	E_2	E_3	E_4	W
E_1	1	3	5	5	0.536
E_2	1/3	1	4	5	0.289
E_3	1/5	1/4	1	3	0.113
E_4	1/5	1/5	1/3	1	0.062

C.R. = 0.094

Table 16 Comparisons to "Bridge 3" node in "Safety"

Bridge 3	M_1	M_2	W
M_1	1	6	0.857
M_2	1/6	1	0.143

C.R. = 0.000

Table 17 Comparisons to "Bridge 3" node in "Safety"

Bridge 3	S_1	S_2	S_3	W
S_1	1	2	1/2	0.311
S_2	1/2	1	1/2	0.196
S_3	2	2	1	0.493

C.R. = 0.052

Table 18 Comparisons to D_1 node in "Alternative" cluster

D_1	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	2	3.1	0.548
Bridge 2	1/2	1	1.6	0.277
Bridge 3	1/3.1	1/1.6	1	0.175

C.R. = 0.001

Table 19 Comparisons to E_1 node in "Alternative" cluster

E_1	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	1/3	1/4	0.126
Bridge 2	3	1	1.5	0.475
Bridge 3	4	1/1.5	1	0.399

C.R. = 0.052

Table 20 Comparisons to E_2 node in "Alternative" cluster

E_2	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	1/5	1/3	0.109
Bridge 2	5	1	2	0.582
Bridge 3	3	1/2	1	0.309

C.R. = 0.004

Table 21 Comparisons to E_3 node in "Alternative" cluster

E_3	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	1/2	1/1.5	0.273
Bridge 2	2	1	3	0.545
Bridge 3	1.5	1/3	1	0.182

C.R. = 0.000

Table 22 Comparisons to E_4 node in "Alternative" cluster

E_4	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	5	3	0.659
Bridge 2	1/5	1	1.5	0.179
Bridge 3	1/3	1/1.5	1	0.162

C.R. = 0.090

Table 23 Comparisons to M_1 node in "Alternative" cluster

M_1	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	5/4	5/3	0.417
Bridge 2	4/5	1	4/3	0.333
Bridge 3	3/5	3/4	1	0.250

C.R. = 0.090

Table 24 Comparisons to M_2 node in "Alternative" cluster

M_2	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	1/2	1	0.250
Bridge 2	2	1	2	0.500
Bridge 3	1	1/2	1	0.250

C.R. = 0.090

Table 25 Comparisons to S_1 node in "Alternative" cluster

S_1	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	1	1.8	0.396
Bridge 2	1	1	1.4	0.365
Bridge 3	1/1.8	1/1.4	1	0.239

C.R. = 0.006

Table 26 Comparisons to S_2 node in "Alternative" cluster

S_2	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	1	3.5	0.444
Bridge 2	1	1	3	0.422
Bridge 3	1/3.5	1/3	1	0.134

C.R. = 0.002

Table 27 Comparisons to S_3 node in "Alternative" cluster

S_3	Bridge 1	Bridge 2	Bridge 3	W
Bridge 1	1	0.8	3	0.421
Bridge 2	1.25	1	1.5	0.388
Bridge 3	1/3	1/1.5	1	0.191

C.R. = 0.091

3.3 Computing Limit Supermatrix

The computing process is as following:

1. Get unweighted supermatrix as shown in Table 28.

Every column in supermatrix is the ranking vector which we get through pairswise comparisons. The supermatrix W is from pairswise comparisons, and every column in the supermatrix is the ranking weight basing some factor.

2. Compute the supermatrix W and normalize it as shown in Table 29.

For the convinnence of the calculation,we need to normalize every column in the supermatrix which can be got through weighting matrix($W_{ij} = a_{ij} w_{ij}$, it is weighting matrix a_{ij} multiply supermatrix w_{ij}).

3. Compute the limit suprematrix $\lim_{k \leftarrow \infty} W^k$ as shown in Table 30

Table 28 Unweighted Supermatrix

		Alternatives			Durability	Economy				Manufacturability		Safety		
		Bridge1	Bridge2	Bridge3	D_1	E_1	E_2	E_3	E_4	M_1	M_2	S_1	S_2	S_3
A	Bridge1	0.000	0.000	0.000	0.548	0.125	0.109	0.272	0.659	0.416	0.250	0.396	0.444	0.421
	Bridge2	0.000	0.000	0.000	0.276	0.475	0.581	0.545	0.178	0.333	0.500	0.364	0.422	0.388
	Bridge3	0.000	0.000	0.000	0.174	0.399	0.309	0.181	0.161	0.250	0.250	0.239	0.133	0.190
D	D_1	1.000	1.000	1.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000	1.000	1.000
E	E_1	0.608	0.599	0.536	0.525	0.494	0.628	0.166	1.000	0.634	0.000	1.000	0.317	1.000
	E_2	0.231	0.204	0.289	0.386	0.376	0.000	0.833	0.000	0.287	0.000	0.000	0.507	0.000
	E_3	0.101	0.108	0.113	0.071	0.079	0.086	0.000	0.000	0.077	1.000	0.000	0.103	0.000
	E_4	0. 060	0. 089	0.062	0.016	0.052	0.285	0.000	0.000	0.000	0.000	0.000	0.073	0.000
M	M_1	0.888	0.857	0.846	0.000	0.000	1.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	M_2	0.111	0.142	0.153	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000
S	S_1	0.548	0.392	0.310	0.637	0.657	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.666
	S_2	0.194	0.224	0.195	0.105	0.196	0.000	0.000	0.000	0.000	0.000	1.000	0.000	0.333
	S_3	0.257	0.383	0.493	0.258	0.146	0.000	0.000	0.000	0.000	0.000	0.000	0.500	0.000

Table 29 Weighted Supermatrix

		Alternatives			Durability	Economy				Manufacturability		Safety		
		Bridge1	Bridge2	Bridge3	D_1	E_1	E_2	E_3	E_4	M_1	M_2	S_1	S_2	S_3
A	Bridge1	0.000	0.000	0.000	0.289	0.058	0.065	0.186	0.476	0.312	0.187	0.197	0.214	0.209
	Bridge2	0.000	0.000	0.000	0.146	0.221	0.345	0.373	0.129	0.250	0.375	0.181	0.204	0.193
	Bridge3	0.000	0.000	0.000	0.092	0.186	0.183	0.124	0.116	0.187	0.187	0.119	0.064	0.094
D	D_1	0.141	0.141	0.141	0.000	0.000	0.132	0.000	0.000	0.000	0.000	0.109	0.106	0.109
E	E_1	0.608	0.149	0.140	0.069	0.000	0.143	0.043	0.277	0.158	0.000	0.145	0.082	0.145
	E_2	0.231	0.055	0.076	0.052	0.156	0.000	0.219	0.000	0.071	0.000	0.000	0.040	0.000
	E_3	0.101	0.032	0.030	0.011	0.022	0.019	0.000	0.000	0.019	0.250	0.000	0.012	0.000
	E_4	0.060	0.026	0.016	0.007	0.000	0.065	0.000	0.000	0.000	0.000	0.000	0.007	0.000
M	M_1	0.039	0.038	0.037	0.000	0.000	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	M_2	0.004	0.006	0.006	0.000	0.000	0.000	0.051	0.000	0.000	0.000	0.000	0.029	0.000
S	S_1	0.302	0.216	0.171	0.253	0.232	0.000	0.000	0.000	0.000	0.000	0.000	0.119	0.164
	S_2	0.107	0.123	0.108	0.028	0.069	0.000	0.000	0.000	0.000	0.000	0.246	0.000	0.082
	S_3	0.142	0.211	0.272	0.050	0.051	0.000	0.000	0.000	0.000	0.000	0.000	0.119	0.000

We denote W_{ij} as the supermatrix W , where W_{ij} reflects the first step priority for the element i to the element j ,the second step priority W^2 can be got from $\sum_{k=1}^{N} w_{ik} w_{kj}$, W^2 is also normalized in column. We will get the limit supermatrix when the number in row is the same through weight matrix W self-multiplying. Then we will stop multiplying weight marix.

First, determine unweighted supermatrix as shown in Table 28.

Second, compute weighted supermatrix as shown in Table 29.

Last, compute limit supermatrix as shown in Table 30.

Table 30 Limit Supermatrix

		Alternatives			Durability	Economy				Manufacturability		Safety		
		Bridge1	Bridge2	Bridge3	D_1	E_1	E_2	E_3	E_4	M_1	M_2	S_1	S_2	S_3
A	Bridge1	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117
	Bridge2	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145
	Bridge3	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087	0.087
D	D_1	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074	0.074
E	E_1	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162	0.162
	E_2	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080	0.080
	E_3	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027	0.027
	E_4	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
M	M_1	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
	M_2	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
S	S_1	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122
	S_2	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078
	S_3	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078	0.078

3．4 **Synthesizing the overall results**

Synthesize to get overall ranking results in the bridge model of ANP as shown in Table 31.

The overall result of Table 31 agrees with the practical analytical results. If we take organic emergency bridge equipment(all the equipment is manufactured in factory, the single member's dimension is small ,the weight is light, the field installation is the connection of pin-connection or bolt-connection), the purchase cost is high, but field installation is convenient. After construction the equipment can be decomposed conveniently. The material can be used for the next convenience bridge manufacturing so for the next convenience bridge, it reduces the purchase cost. If the deck takes the organic equipment, the field installation is convenient, but the deck integration is bad and the economy is bad. If the deck is made of organic equipment that is manufactured in field, it will add the fabrication cost. Field installation is convenient, the deck integration is good, and the durability is also well. So if the length of the convenience bridge is long, the beam of the main load carrying structure takes the organic equipment, the deck is made of the organic equipment which is manufactured in field. Then the safety and durability are ensured and can get the more economic. So the ANP method is suitable to evaluate design alternatives for emergency bridge.

Table 31 Synthesizing the Overall Results

Name	Graphic	Normals	Ranks
Bridge 1		0.325	2
Bridge 2		0.421	1
Bridge 3		0.254	3

4.Conclusions

The assessment of the design alternatives of the emergency bridge is an important decision-making, and it is usually met with. The assessment model that we take is scientific reasonable or not will influence the scientific of the decision-making result. For the complex decision problem, because many factors have the dependence and feedback, so we take the ANP is suitable to assess design alternatives for emergency bridge.

REFERENCES

Huang Shaojin, Liu Mosheng(2004). *Multifunctional Operation Manual of Prefabricated Highway Steel Bridge*,.China Communications Press, Beijing.

Sun Hongcai,Tian Ping(2001). The Analytic Network Process (ANP) & scientific decision-making, in: Theory & Method of Decision-making Science. Beijing: China Ocean Press, 3-8.

Thomas L. Saaty(2001). Decision Making with Dependence and Feedback: The Analytic Network Process, Pittsburgh, PA: RWS Publications.

Wang Lianfen, Xu Shubai(1990). *The Theory of the Analytic Hierarchy Process*. China Renmin University Press, Beijing.

Xu Shubai(1988). *The Principle of the Analytic Hierarchy Process.* Tianjin Unversity Press, Tianjin.

Zhu Yongzhuo, Xu Guanyao, Gou Mingkang(2004). Design and realization of ZB-200 Prefabricated Highway Steel Bridge. *Traffic Engineering and Technology for National Defence*, 1, 14-18.