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AHP IN CHINA

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1. INTRODUCTION

The Analytic Hierarchy Process (AHP), a multiple criteria decision making approach, was established in the late 1970s by T. L. Saaty at Pittsburgh University, USA. In this approach, judgment factors that can be used for evaluating alternatives are arranged in a hierarchical structure. And the alternatives are ranked with the aid of the judgment matrices which are given to decision analysts. Since its theory based on hierarchical structure is very suitable for the traditional decision framework commonly used in China, especially for those to deal with social, economic or technological decision problems, AHP has been widely accepted and employed by Chinese decision-making analysts. We combine it with qualitative and quantitative analysis, and transform non-structured problems into structured problems. Since 1982 that marked the introduction of AHP to China, both the research and the application in AHP have made remarkable progress, showing its strength in decision making.

2. GENERAL SITUATION

AHP was first introduced to China during the First Symposium on Energy Development Strategy in 1982. Initiated by Professor Bao Liu, professors Shubai Xu and Jinsheng He conducted a seminar on AHP in 1983, and held training courses at Tianjin University in 1986. In addition, Hongxun Jia and Hongcai Sun, senior engineers of Beijing System Engineer Institute of Engineer Equipment, taught five nationwide courses on AHP. Similar courses were held in several provinces where researchers were trained. To promote the Analytic Network Process (ANP), a general theory to determine the one with dominating influence among several alternatives under certain criteria, Hongcai Sun taught ANP at Nanjing University of Aeronautics and Astronautics in 2002, at China University of Political Science and Law in 2004, and at Beijing Jiaotong University in 2003. Nowadays, nearly one hundred higher educational institutions offer AHP courses. Many postgraduate and doctoral students select AHP as their research directions and degree essays topics. With all the endeavor and efficient work, a large academic group has engaged in studying and AHP applications have been growing significantly in China.

2.1 Societies and Academic Activities

In 1988, aiming at coordinating and organizing AHP research in China, a national AHP promotion team led by Shubai Xu was founded at Tianjin University and the First International Symposium on AHP was held. In the same year, an AHP seminar given by foreign scholars (including T. L. Saaty) was held in Beijing. Later, a special academic group on AHP under the Society of Systems Engineering of China (SSEC) was established, hosted by Beijing System Engineer Institute of Engineer Equipment. Guizhong Wang and Hongcai Sun were selected as general secretary and vice-general secretary respectively. In 1990, 16 Chinese scholars participated in the second international symposium on AHP in Pittsburgh, USA. In China, the First Academic Meeting on AHP was held by Beijing System Engineer Institute of Engineer Equipment.

In 1992, the special academic group on AHP was renamed as the Decision Science Committee, as one branch of SSEC. Wang Gui Zhong is now the director, and Hongcai Sun is the general secretary. In 1993, professor Saaty was invited by the committee to give a presentation on “The recent progress of AHP” in Beijing. Since the inauguration of the Decision Science Committee, four (2nd to 5th) Academic Meetings on AHP were held by Beijing System Engineer Institute of Engineer Equipment in 1992, 1996, 2001, and 2003 respectively.

2.2 AHP Journal and Publications

Decision and the Analytic Hierarchy Process is a periodical publication by the Decision Science Committee. It is the first journal that specially introduces and promotes AHP in China. With the inaugural issue in 1990, it has published 7 issues and widely influenced the AHP application and decision science field. It offers Chinese researchers and practitioners chances to present their research work on AHP and has become a prestigious journal.

In addition, we have published a series of books on fundamentals of decision making with AHP. The book “The Analytic Hierarchy Process” by T. L. Saaty and translated by Xu Shu Bai was translated into Chinese in 1989.

The above efforts have greatly pushed the research and practice of AHP in China. In a survey, more than 914 papers on AHP have been published in various Chinese journals, such as Journal of Systems Engineering, Theories and Applications in Systems Engineering, Journal of Operational Research, Decision and Decision Support Systems, journal of Management Science, journal of the Soft-Sciences, etc.

3. RESEARCH WORK ON AHP THEORY

As a new decision theory and methodology, AHP inevitably has a lot of issues to be further investigated. We have systematically conducted a series of studies that emphasize on demonstrating and completing a general framework of AHP.

In accordance with the theory of dynamic ranking, we put forward a new model that is different from the original one in constructing judgment matrix. The new model is also suitable for those dynamic judgment matrices that have more than four ranks. It addresses the problem that the original model could not generate solutions of characteristic roots and expands AHP.

The research on Group AHP (GAHP) is one active research topic in China. Since decision making is a process in which a group of people are involved, it is very important to synthesize group preferences. Having widely reviewed related issues, such as handling group judgments, picking extreme preferences, and determining reliability of information, we have developed correlative concepts and methods for getting squired sum of weights, calculating geometric average values of elements in the judgment matrices, synthesizing weights, as well as constructing functions on judgment information from expert panels based on Shannon’s information theory. Moreover, based on the Fuzzy theory, we have proposed some Fuzzy AHP methods that apply Fuzzy theory to build judgment matrices and to infer about comprehensive scales and priority of alternatives.

On the research of ranking theory, we have made modifications to the gradient eigenvector method (GEM) to get the weight vectors when there is a wide inconsistency in judgment matrices. In addition, we have identified the sufficient condition for keeping restrict order of a priority when a set of new elements are introduced to the priority. To deal with the consistencies of judgment matrices, we modified the original consistency indices (C. I. and C. R) by taking a test in which the average random consistency indices are associated to matrices with different size of 1 to 15 levels.

Considering AHP as a complementary method for Operational Research (OR), we have explored the applied conditions and approaches, and demonstrated the performance of applying AHP to Multiple Attributes Decision Making (NADM). Furthermore, we have tried to combine AHP with the Data Envelopment Analysis (DEA) to evaluate relative efficiencies of decision making components.

Interpretation of AHP is part of our research work. With the use of tensor analysis, we have given an interpretation and a model of AHP in the form of tensors. We substituted the model for hyper-matrix to describe those decision problems with feed back hierarchical systems and simplified the analysis process. Moreover, we have established a series of usage patterns of applying AHP to some conventional analyses in terms of costs and benefits, linear programming, dynamic programming and DEA.

4. APPLICATION OF AHP IN CHINA

In China, AHP has been used in many decision activities in economy, energy, management, environment, traffic, agriculture, industry, military missions, etc. The more than 914 papers published on AHP are exemplified in the following applications:

In energy development, Le Wei Liang and Wang Ying Luo established an AHP-based model to determine a reasonable investment proportion, which directed the development and management of diverse mining fields in Shan Xi province. Xu Shu Bai and He Jin Sheng analyzed costs and benefits of the energy reserve forms for civil use in Tianjin. Zhu Guang Yuan and Ge Chang Yi built a model for evaluating agricultural energy policies. Wu Jun Hui also studied the involved problems in energy management and control.

In strategy planning, HongCai Sun developed a long-term planning program on engineering equipment in 2000. Cheng Sou Tao studied a target application system in which plans for developing a series of major weapons were ranked. Yang Jia Ye proposed a model on economic development strategy in Xinyang city. Wang Wen Juan established a model for selecting key industries for Beijing city. He Jin Sheng studied the industrial project construction in Tianjin by using AHP. Yang Jian Mei designed a comprehensive AHP-MLP model for analyzing industrial project construction. Yang Yongqing, Xu Xianyun studied the creation of judgment matrix in the Group AHP method with mixed factors, which may be qualitative or quantitative, and generated indirect estimation of the judgment matrix with these factors.

In economic analysis and forecasting, Fu Ding De ranked industrial superiority in Zhejiang province. Meng Zhao Zheng developed an evaluation model for forecast about petroleum resources. Hongcai Sun combined AHP with cybernetics theory to build a model for dissemination of urban population in response to natural disasters. Xie Guang Bei solved the decision problem to allocate various industries in the Tianjin economic development zone.

In systematic evaluation of equipments, Tian Mu Ling developed a hierarchical model to evaluate alternatives for designing a new armed vehicle. Jia Hong Xun built an evaluation model for the overall performances of engineering equipment by combining AHP with Multiple Attribute Utility Theory (MAUT). Liu Jun, Zhou Yong from Shandong Mining Institute, and Shi Yuzhuo from Yanzhou Mining Bureau, applied AHP method to quality optimization in enterprises. Han Baoming from the Department of Transportation Management Engineering, Northeastern Jiaotong University, used AHP to analyze different operating plans for Datong-Qinhuangdao railway route, the first electric heavy-haul double-line railway in China, in order to reach the designed capacity as soon as possible.

In operational applications in agriculture, researchers have developed decision models for national “Spark Project,” and made analysis including agricultural development classification, crop plantation proportions and rational scales, livestock products and regional ecological balance.

In management of scientific researches, researchers emphasized on constructing criterion systems for evaluating scientific research achievements, selecting scientific research projects and determining regional overall scientific and technological strengths.

In intellectual talent evaluation and planning, AHP has been used to evaluate multiple objective weights in the model of planning higher education in China. In addition, several assessment and evaluation systems for government workers employ AHP as the main analysis tool.

5. CASES OF AHP APPLICATIONS IN CHINA

5.1 Application of the Analytic Network Process to Design Alternative Evaluation of Bridges

5.1.1 Introduction

China is renowned for her beautiful landscape. But the many mountains and rivers that contribute to this beauty also impede land transport and communication. The deep, broad river known in China as the Long River (also called the Yangtze River) flows in a torrent from west to east across the middle of the land and was considered in ancient times an impassable “natural chasm.” Communications were difficult in southwestern China where mountain towers over mountain and rivers crisscross each other. As the Tang Dynasty poet Li Bai (701-762) put it in one of his poems:

> “ *Travel to Sichuan*
> *Is as hard as the climb to heaven.*”

Man, however, can conquer nature. The diligent and courageous Chinese people have accomplished a great deal in their centuries of struggle against nature. To facilitate communications, Chinese technicians and working people erected bridges of various types across the rivers and deep canyons. Among these, Chaochow Bridge shown in Figure 1 is a masterpiece in ancient time, and Jiangyin Yangtze River Bridge shown in Figure 2 a masterpiece in modern time.

Figure 1 Chaochow Bridge

Figure 2 Jiangyin Yangtze River Bridge

A bridge is a common and yet special structure. Common, because it is indispensable for travel across water courses and gorges, which are found everywhere; special, because, built as a road high above the ground, it needs particular materials and should be planned and constructed according to scientific and artistic designs. A country's bridge construction, therefore, invariably shows the extent of her economic and cultural achievements.

In order to improve bridge design quality and reduce risks for bridge construction, design alternative evaluation is an important decision making process before a new bridge may be built. Often in this decision process the action is to select the best of three bridge designs under the same requirements on span and total length, load carrying capacity, width of carriageway, construction speed, central reserve, construction limitation, clearances on bridge decks and clearances under bridge, and aseismic consideration. The decision made in this process directly affects the whole life cost of the bridge being targeted.

In view of the worldwide trend, it becomes more significant to develop a strategy and a systematic evaluation method of the overall performance of bridge design alternatives, because the evaluation method applied directly affects the decision made. Although various techniques exist for decision making modeling, the Analytic Network Process (ANP) was chosen for this study. ANP allows us to quantify important bridge factors, considers whether a factor influences another or is influenced by another, that is to say, dependence and feedback. Based on the importance of various decision criteria, ANP creates a super-matrix and synthesize to get the bridge design ranking results by using an ANP bridge model. ANP is a good evaluation method as shown in the example below.

5.1.2 Evaluation Factors of Bridge Design Alternatives

Standards for strength, durability, constructability, usability, functionality and safety reflect the volumes of regulations that govern the design and construction of new bridges. While designing a new bridge, these factors such as locations where the bridge will be built, span and total length of the bridge, height of deck, load-carrying capacity, sway and deflection limits, clearance for recreational navigation on the river and for access roads along the river banks is known. Factors must be compared as shown in Figure 3.

1. Safety. As with a new construction project, safely is a matter of life or death. According to our native system, safety quality of engineer project is tenure. Safety is of primary importance. That is to say, safety has the highest priority. Safety includes strength and stiffness.

2. Durability. Having relations with primary materials of bridges, durability that is a very important characteristic can be described by crossing life. For example, steel material has its durability and fast erection.

3. Economy. Economy has relations with costs of material, production and installation in the field.

4. Constructability. It includes manufacture technology in the factory and construction speed in the field. Good constructability shows good manufacture technology and facilitates construction. From the view of scientific analysis, time is money and time is benefit, because reducing bridge constructing period can assure that the bridge will has been completed ahead of schedule. After having built the bridge, we can gain economic benefit and social benefit. So, vehicle crossing ahead of schedule is very valuable.

5. Aesthetics. A good design makes the bridge itself an artwork and improves the scene of the surroundings around the bridge.

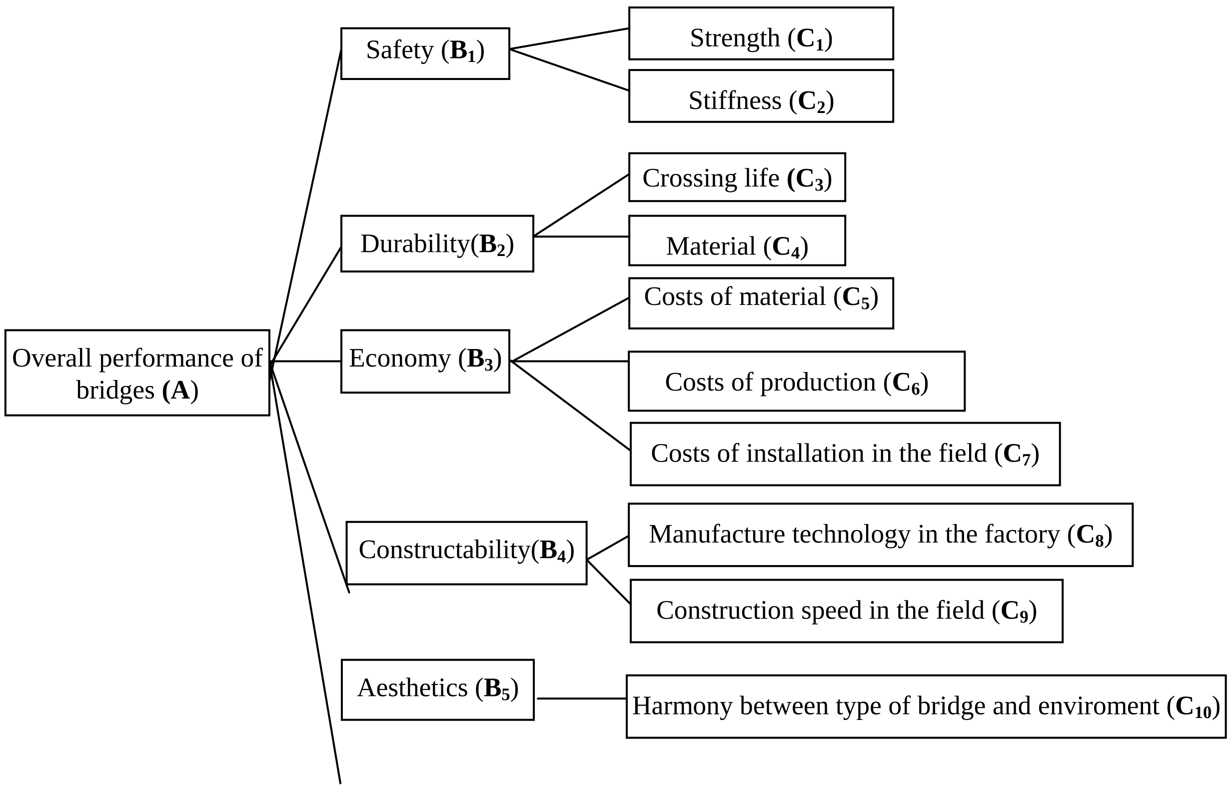

Figure 3. Overall performances of bridges

Designers must consider carefully the comparative advantages of various alternatives. For example, a truss bridge may be stiffer than a beam bridge but slower to be constructed.

5.1.3 Steps of Applying ANP to Evaluating Bridge Design Alternatives

5.1.3.1 Quantifying Bridge Elements

The degree that these factors influence the overall performance of a bridge is different. In order to normalize all elements, we quantify all bridge elements using a score range from 1 to 9. The best performance score 8 or 9, the better 6 or 7, the good 4 or 5. The following is a case of selecting bridge design alternatives for the express highway from Hangzhou to Qian Dao Lake in Zhejiang province. ANP method was adopted in order to evaluate three design alternatives, i.e. Bridge design 1, 2 and 3. The overall scores are shown in Table 1. For example, for the construction speed $\mathbf{C_9}$, the first alternative, Bridge 1 needs 3 years and scores 3, Bridge 2 needs 2 years and scores 6, and Bridge 3 scores 9 for 1 year.

Table 1 Score values of all elements

Alternative	*C₁*	*C₂*	*C₃*	*C₄*	*C₅*	*C₆*	*C₇*	*C₈*	*C₉*	*C₁₀*
Bridge 1 (**F**)	9	9	9	5	5	5	2	5	3	3
Bridge 2 (**S**)	7	6	8	5	7	6	5	4	6	6
Bridge 3 (**T**)	5	3	7	5	9	8	9	3	9	6

5.1.3.2 Building Bridge Model of ANP

Analyzing and comparing, we build an ANP model, feedback network with inner dependence loop, as shown in Figure 4.

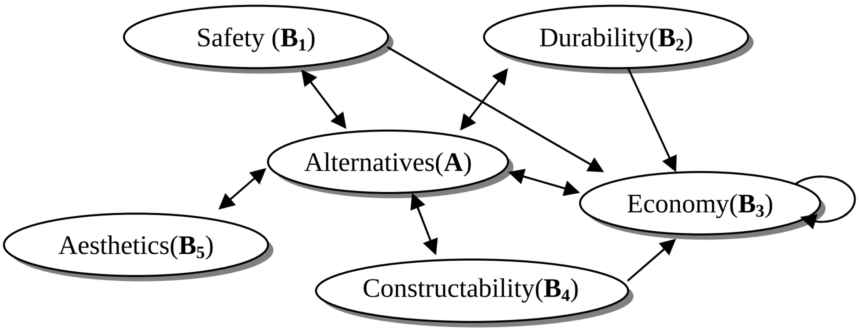

Figure 4. Dependencies for the bridge model

5.1.3.3 Computing Weight

We compute weights by pairwisely compare bridge alternatives regarding each elements, for example, strength (**C_1**), stiffness (**C_2**), crossing life **(C_3**), material (**C_4**), costs of material (**C_5**), and so on. Computation results are shown in Table 2 to Table 11 as follows.

Table 2 Weight with respect to strength (C_1)

C_1	*F*	*S*	*T*	*W*
F	1	1.28571	1.8	0.42857
S	0.77778	1	1.4	0.33333
T	0.55556	0.71429	1	0.23810

Table 3 Weight with respect to stiffness (C_2)

C_2	*F*	*S*	*T*	*W*
F	1	1.5	3	0.5
S	0.66667	1	2	0.33334
T	0.33333	0.5	1	0.16666

Table 4 Weight with respect to crossing life (C_3)

C_3	*F*	*S*	*T*	*W*
F	1	1.125	1.28571	0.37500
S	0.88889	1	1.1429	0.33333
T	0.77778	0.875	1	0.29167

Table 5 Weight with respect to material (C_4)

C_4	*F*	*S*	*T*	*W*
F	1	1	1	0.33333
S	1	1	1	0.33333
T	1	1	1	0.33333

Table 6 Weight with respect to costs of material (C_5)

C_5	*F*	*S*	*T*	*W*
F	1	0.71429	0.55556	0.23810
S	1.4	1	0.77778	0.33333
T	1.8	1.28571	1	0.42857

Table 7 Weight with respect to costs of production (C_6)

C_6	*F*	*S*	*T*	*W*
F	1	0.83333	0.625	0.21316
S	1.2	1	0.75	0.31579
T	1.6	1.33333	1	0.42105

Table 8 Weight with respect to costs of installation (C_7)

C_7	*F*	*S*	*T*	*W*
F	1	0.4	0.22222	0.12848
S	2.5	1	0.55556	0.37115
T	4.5	1.8	1	0.50037

Table 9 Weight with respect to manufacture technology (C_8)

C_8	*F*	*S*	*T*	*W*
F	1	1.25	1.66667	0.41890
S	0.8	1	1.33333	0.30447
T	0.6	0.75	1	0.27663

Table 10 Weight with respect to construction speed (C_9)

C_9	*F*	*S*	*T*	*W*
F	1	0.5	0.33333	0.16666
S	6	1	0.66667	0.33334
T	3	1.5	1	0.5

Table 11 Weight with respect to harmony (C_{10})

C_{10}	*F*	*S*	*T*	*W*
F	1	0.5	0.5	0.20000
S	2	1	1	0.40000
T	2	1	1	0.40000

5.1.3.4 Computing the Super-matrix

Firstly, we determine the unweighted super-matrix as shown in Table 12. Secondly, we compute the weighted super-matrix as shown in Table 13. Lastly, we compute the limit super-matrix as shown in Table 14.

Table 12 Unweighted super-matrices

		Design Alternatives(D)			*B_1*		*B_2*		*B_3*			*B_4*		*B_5*
		Bridge1	*Bridge2*	*Bridge3*	*C_1*	*C_2*	*C_3*	*C_4*	*C_5*	*C_6*	*C_7*	*C_8*	*C_9*	*C_{10}*
D	Bridge1	0.00000	0.00000	0.00000	0.42857	0.50000	0.37500	0.33333	0.23810	0.26316	0.12848	0.41889	0.16667	0.2000
	Bridge2	0.00000	0.00000	0.00000	0.33333	0.33333	0.33334	0.33333	0.33333	0.31579	0.37115	0.30449	0.33333	0.4000
	Bridge3	0.00000	0.00000	0.00000	0.23810	0.16667	0.29166	0.33333	0.42857	0.42105	0.50036	0.27662	0.50000	0.4000
B_1	C_1	0.33333	0.50000	0.50000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	C_2	0.66667	0.50000	0.50000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B_2	C_3	0.90000	0.90000	0.50000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	C_4	0.10000	0.10000	0.50000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B_3	C_5	0.50000	0.50000	0.50000	1.00000	0.00000	0.33333	0.00000	0.00000	0.00000	0.00000	0.00000	0.33333	0.00000
	C_6	0.33333	0.33322	0.33322	0.00000	0.00000	0.33333	0.00000	0.50000	0.00000	0.00000	0.00000	0.33333	0.00000
	C_7	0.16667	0.16675	0.16675	0.00000	0.00000	0.33333	0.00000	0.50000	0.00000	0.00000	0.00000	0.33333	0.00000
B_4	C_8	0.60000	0.50000	0.50000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	C_9	0.40000	0.50000	0.50000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B_5	C_{10}	1.00000	1.00000	1.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Table 13 Weighted super-matrix

		Design Alternatives(D)			*B_1*		*B_2*		*B_3*			*B_4*		*B_5*
		Bridge1	*Bridge2*	*Bridge3*	*C_1*	*C_2*	*C_3*	*C_4*	*C_5*	*C_6*	*C_7*	*C_8*	*C_9*	*C_{10}*
D	Bridge1	0.00000	0.00000	0.00000	0.21429	0.50000	0.18750	0.33333	0.11905	0.26316	0.12848	0.41889	0.08333	0.2000
	Bridge2	0.00000	0.00000	0.00000	0.16667	0.33333	0.16667	0.33333	0.16667	0.31579	0.37115	0.30449	0.16667	0.4000
	Bridge3	0.00000	0.00000	0.00000	0.11905	0.16667	0.14583	0.33333	0.21429	0.42105	0.50036	0.27662	0.25000	0.4000
B_1	C_1	0.11111	0.16667	0.16667	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	C_2	0.22222	0.16667	0.16667	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B_2	C_3	0.23333	0.23333	0.12963	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	C_4	0.02593	0.02593	0.12963	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B_3	C_5	0.14815	0.14816	0.14816	0.50000	0.00000	0.16667	0.00000	0.00000	0.00000	0.00000	0.00000	0.16667	0.00000
	C_6	0.09877	0.09873	0.09873	0.00000	0.00000	0.16667	0.00000	0.25000	0.00000	0.00000	0.00000	0.16667	0.00000
	C_7	0.04938	0.04941	0.04941	0.00000	0.00000	0.16667	0.00000	0.25000	0.00000	0.00000	0.00000	0.16667	0.00000
B_4	C_8	0.04444	0.03704	0.03704	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
	C_9	0.02963	0.03704	0.03704	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
B_5	C_{10}	0.03704	0.03704	0.03704	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000

Table 14 Limit super-matrix

		Design Alternatives(D)			*B_1*		*B_2*		*B_3*			*B_4*		*B_5*
		Bridge1	*Bridge2*	*Bridge3*	*C_1*	*C_2*	*C_3*	*C_4*	*C_5*	*C_6*	*C_7*	*C_8*	*C_9*	*C_{10}*
D	Bridge1	0.13470	0.13470	0.13470	0.13470	0.13470	0.13470	0.13470	0.13470	0.13470	0.13470	0.13470	0.13470	0.13470
	Bridge2	0.14515	0.14515	0.14515	0.14515	0.14515	0.14515	0.14515	0.14515	0.14515	0.14515	0.14515	0.14515	0.14515
	Bridge3	0.15097	0.15097	0.15097	0.15097	0.15097	0.15097	0.15097	0.15097	0.15097	0.15097	0.15097	0.15097	0.15097
B_1	C_1	0.06432	0.06432	0.06432	0.06432	0.06432	0.06432	0.06432	0.06432	0.06432	0.06432	0.06432	0.06432	0.06432
	C_2	0.07928	0.07928	0.07928	0.07928	0.07928	0.07928	0.07928	0.07928	0.07928	0.07928	0.07928	0.07928	0.07928
B_2	C_3	0.08487	0.08487	0.08487	0.08487	0.08487	0.08487	0.08487	0.08487	0.08487	0.08487	0.08487	0.08487	0.08487
	C_4	0.02683	0.02683	0.02683	0.02683	0.02683	0.02683	0.02683	0.02683	0.02683	0.02683	0.02683	0.02683	0.02683
B_3	C_5	0.11262	0.11262	0.11262	0.11262	0.11262	0.11262	0.11262	0.11262	0.11262	0.11262	0.11262	0.11262	0.11262
	C_6	0.08733	0.08733	0.08733	0.08733	0.08733	0.08733	0.08733	0.08733	0.08733	0.08733	0.08733	0.08733	0.08733
	C_7	0.06608	0.06608	0.06608	0.06608	0.06608	0.06608	0.06608	0.06608	0.06608	0.06608	0.06608	0.06608	0.06608
B_4	C_8	0.01695	0.01695	0.01695	0.01695	0.01695	0.01695	0.01695	0.01695	0.01695	0.01695	0.01695	0.01695	0.01695
	C_9	0.01496	0.01496	0.01496	0.01496	0.01496	0.01496	0.01496	0.01496	0.01496	0.01496	0.01496	0.01496	0.01496
B_5	C_{10}	0.01596	0.01596	0.01596	0.01596	0.01596	0.01596	0.01596	0.01596	0.01596	0.01596	0.01596	0.01596	0.01596

5.1.3.5 Synthesizing the overall results

We synthesize to get overall ranking results in the bridge model of ANP as shown in Table 15. From view of Table 15, we can know the third alternative is the best one of the three design alternatives. The result is in line with the truth. The truth is that the project manager adopted the third alternative.

Table 15 Bridge ranking results

Alternatives	Graphic	Ideals	Normals	Totals
Bridge 1		0.892231	0.312661	0.134697
Bridge 2		0.961437	0.336913	0.145145
Bridge 3		1.000000	0.350426	0.150967

5.2 Application of the Analytic Network Process to Evaluation of Bid for Emergency Bridge Project

5.2.1 Introduction

Express highway construction is an important part of state infrastructure facilities construction in China. In order to speed up construction, a lot of temporary or emergency prefabricated steel bridges may be used ranging from substructures to entire bridges, which proves to be a best practice. The prefabricated steel bridges can be manufactured offsite under controlled conditions, and brought to the working site in a ready-to-install form. Using these prefabricated steel bridges reduces the traffic congestion and environmental impacts of bridge construction projects and improves construction zone safety for both workers and drivers. And because prefabrication can be accomplished in a controlled environment offsite, without the limitations that a job site may present, constructability is improved, quality is increased, and the costs are lowered. Costs can particularly be reduced where sophisticated techniques are needed to perform cast-in-place construction, such as for long water crossings or multi-level structures.

The famous temporary or emergency prefabricated steel bridge is known for Bailey Bridge, also called as Prefabricated Highway Steel Bridge (PHSB) in China, was originally developed by Sir Donald Bailey and was widely used during the World War II and ever since then. The Bailey Bridge was designed as a universal unit-construction military bridging system, with the Bailey panel as its basic component as shown in Figure 5.

Figure 5. Illustrations of Prefabricated Highway Steel Bridge (PHSB)

The great advantage of the bridging system lies in its use of these standard interchangeable components, which, combined with the simplicity of component design, can be erected in a short time by unskilled labor under limited supervision by specialist. The Bailey panel, the basic component, is made of high-tensile steel. The panels are connected with panel pins and chord bolts to produce a series of composite girders with varying strengths for complex loading conditions and construction requirements, for example, as shown by the temporary bridges in Figure 6.

Figure 6. Illustrations of temporary Bridges

In China, PHSB bridges are produced by tens of factories in all over country. Some factories manufacture PHSB bridges following the ISO9001 standards, the international benchmark of quality manufacturing and design. Sometimes the quality cannot be guaranteed because the factories manufacture PHSB bridges with unskilled laborers to lower costs. To consider the above situation, to uphold transparency and accountability, and to achieve equity, effectiveness, efficiency and economy in its procurement of PHSB, customers often adopt bidding procedures.

5.2.2 Composition of Bids & Awards Committee

Each bridge project agency shall create a Bids and Awards Committee in the executive office, which shall be responsible for determination of eligibility, conduct of bidding, evaluation of bids, qualification post-evaluation of the lowest calculated bid, and recommendation of awards and contracts. The record keeping, planning and management of the procurement process shall be designated to appropriate units of the procurement agency.

The Bids and Awards Committee shall be composed of the following:

- Chairman - At least the third ranking official of the procurement agency.
- Executive Officer and Secretary – Official officers of the corporation.
- Members - Technical members designated by the head of agency, with knowledge and experience in the bridges. At least one member must understand the features of the bridges concerned and know very well manufacturing factories.

5.2.3 Preparation of Bid/Tender Documents

To ensure fair competition, the Bid/Tender Documents shall describe clearly and precisely the nature of the emergency bridges for which bids are to be invited, the technical standards/requirements that must be met, the location and date of delivery or installation, the warranty and maintenance requirements, the method and criteria to be employed in the evaluation and comparison of bids, and other pertinent terms.

1. The Instructions to Bidders, which establish the rules of the bidding, shall be as much as possible to be clear and comprehensive to all prospective bidders and shall include at the minimum the following information: a. General Description of the emergency bridges to be provided, including site location and other pertinent project information. b. Scope of Bids, whether bidders are required to bid for the entire contract or are permitted to bid for parts of it (alternative contract options). c. Bid Submission Procedures and Requirements, which shall include information on the language to be adopted in the preparation of the bids, the manner of submission, the number of copies of bid proposals to be submitted aside from the original, pertinent addresses such as where the bids are to be submitted, deadline for the submission of bids, permissible mode of transmission of bid proposals, the exact place, date and time of opening of bids, except in the case of the two (2) stage bidding where the exact place, date and time of bid opening shall be announced as prescribed by the Bids and Awards Committee. d. Terms of Delivery, which shall refer to the basis/currencies and applicable exchange rates on which the bid prices are to be quoted and on what terms the contract is to be awarded. e. Bid and Bid Security Validity Period, which shall consider the time that will be required to examine and evaluate all bids, select the successful bidder, obtain the necessary approvals, including the time required to notify the successful bidder of the award of contract in his favor. f. Method and Criteria for Bid Evaluation that will be adopted. g. Pre-bid Conference schedule where applicable.

2. The Conditions of Contract shall contain the provisions that clearly define the basic and legal responsibilities of and relationships between the involved parties. Provisions for bonds, guarantee, warranty obligations of the manufacturer, form of warranty and warranty period, insurance, liquidated damages, taxes and duties, force majeure or fortuitous events, contract termination, and resolution of disputes including arbitration procedures in addition to the general conditions and supplementary conditions suited to the nature of the emergency bridges, should be included.

3. The Technical Specifications shall describe all the essential features of the members of bridges to be procured and should state that any non-conformity to these essential features shall be treated as a major deviation. Drawings should be consistent with the text of the technical specifications. If particular standards to which emergency bridges must comply are cited, the specifications shall state that emergency bridges meeting *Technical Standard of Highway Engineering* and *General Code for Design of Highway Bridges and Culverts*, which ensure an equal or higher quality that the standards mentioned will also be accepted. Specifications should be based on performance requirements, and, as a general rule, reference to brand names, catalogue numbers.

5.2.4 Invitation to Apply for Eligibility and to Bid

Invitation to Apply for Eligibility and to Bid for local competitive bidding shall be publicly advertised at least 14 days before the deadline for submission of eligibility and bid requirements. For procurement methods other than the open competitive procedure, public advertisement of the Invitation to Apply for Eligibility and to Bid may be dispensed with.

Prospective bidders shall be given ample time to examine the forms for application for eligibility and the bid/tender documents and to prepare their respective bids. To provide ample time, the concerned Bids and Awards Committee shall make available upon payment, if applicable, the documents from the time the Invitation to Apply for Eligibility and to Bid is first advertised.

Supplemental bulletins may be issued to prospective bidder, for purposes of clarifying any provision of the bidding document. Any modification to the bid/tender documents should be identified as an amendment. Such bulletins containing amendments and/or clarifications of certain provisions of bid documents shall be sent by mail, by fax, including extension of the deadline set for the receipt of bids if needed.

5.2.5 Determination of Eligibility of Prospective Bidders

The capabilities and resources of prospective bidders shall be initially assessed, subject to post-evaluation of qualification, to determine if they meet the requirements for eligibility. The determination of eligibility of prospective bidders shall be based on the submission of the following documents as specified hereunder:

A. Legal Documents. Current licenses/permits including registration with Department of Industry and Commerce or with Securities and Exchange Commission.

B. Technical Documents - prospective bidder's statement of similar contracts/sales completed in at least the last two years, as prescribed by the agency in the Invitation to Apply for Eligibility and to Bid. “Similar” contracts shall be defined by the concerned agency/corporation in the Invitation to Apply for Eligibility and to Bid. The bidder's documents shall include, for each contract, type of materials sold, amount of contract, end user's acceptance, name of contract, date of contract, date of delivery, and specification of whether prospective bidder is a manufacturer.

C. Financial Documents - audited financial statements, stamped “received” by the Bureau of Internal Revenue, for the required calendar years.

The eligibility of prospective bidders shall be determined using simple “pass/fail” criteria and shall be classified finally as either “eligible” or “ineligible.” If the prospective bidder is rated "passed" for all the above requirements, it shall be considered eligible. If the prospective bidder is rated “failed” in any of the above requirements, it shall be considered ineligible.

If only one bidder is found to be eligible, or that only one bidder responds to the Invitation to Apply for Eligibility and to Bid, the concerned agency shall recognize a lone eligible bidder as valid.

5.2.6 Pre-bid Conferences

The bidders shall bear all costs in the preparation of their bids. The pre-bid conference shall discuss technical specifications, legal requirements, financial requirements, production capability requirements, delivery schedule, and after-sales service requirements

5.2.7 Bid Receipt, Opening, and Tabulation

Bids shall be received, publicly opened and tabulated at a designated time and place by an employee of the Board or other designated individuals.

Prospective bidders shall submit their application for eligibility and bid documents simultaneously by the specified deadline for the submission of the eligibility and bid packages. The eligibility application shall be sealed and contain the documents required in section 5.2.5. The bid package shall be sealed and contain the documents required in section 5.2.5.

- Single-stage bidding: Prospective bidders shall submit simultaneously two envelopes, one containing eligibility requirements and the other containing bidding documents.
- Two-stage bidding: Prospective bidders shall submit their eligibility applications first during the first stage of the bidding. Eligible bidders who are interested to bid shall submit their bidding documents in two sealed envelopes during the second stage of the bidding.

The eligibility applications of prospective bidders shall be opened first to determine eligibility of prospective bidders. In case any of the requirements specified in section 5.2.5 are missing from the eligibility envelope, the Bids and Awards Committee shall declare the prospective bidder as “ineligible” to bid. Bid packages shall immediately be returned unopened to ineligible bidders in case of simultaneous submission of eligibility and bid envelopes.

In case of single-stage bidding variation and two-stage bidding, the first bid packages of eligible bidders shall be opened to determine the bidders’ compliance with requirements. In case any of the requirements are missing, the Bids and Awards Committee shall rate the bid as “failed” and immediately return to the bidder its second bid envelope unopened. The second envelopes of the remaining eligible bidders shall be opened immediately for those whose first bid envelopes were rated “passed.” In case any of the requirements in the second envelope are missing or if the proposed price exceeds the approved budget for the contract, the Bids and Awards Committee shall rate the bid concerned as “failed.”

Only bids whose envelopes are all rated as “passed” shall be evaluated. The Bids and Awards Committee shall determine the lowest calculated responsive bid in the following manner:

1. The first step is to determine whether each eligible bid complies with the submission requirements. The Bids and Awards Committee shall rate a bid “passed” only if it complies with all the requirements and the proposed price does not exceed the approved budget for the contract.

2. The second step is to establish the calculated prices of all bids rated “passed” in the first step. The Bids and Awards Committee shall then rank the calculated prices from lowest to highest.

3. The third step is the qualification post-evaluation of the bidder with the lowest calculated price based on the results of the above evaluation. This shall be done in accordance with the provisions hereof.

5.2.8 Bid Evaluation

Prior to bid evaluation and comparison, bids received shall be examined using "pass/fail" criteria, to determine submission of the following: the bidding prices in the bill of quantities, the installation and the maintenance costs (if applicable), bid securities as to form, amount, and validity period, authority of signatory, production/delivery schedule, person labor requirements, after-sales service/parts, technical specifications, credit line commitments or cash deposit certificate, and other non-discretionary criteria as stated in the Instructions to Bidders.

The above requirements shall be submitted in the following manner: one sealed bid envelope for single stage bidding; two sealed bid envelopes for single stage bidding variation; and at least two sealed envelopes for two stage bidding.

5.2.8.1 Selection of Bid Evaluation Methods

There are two methods that are frequently used by practitioners, namely lowest price method and synthesized method. As denoted by the name, the lowest price method is straightforward: the lowest price wins the bid. Its oversimplicity receives many criticisms from researchers and decision makers, and the practices indicate that sometimes lowest prices just can not provide satisfactory outcomes. The other method, synthesized evaluation method, is relatively more complicated. A committee will be formed to evaluate the bidders from many perspectives, such as reputation etc. Although it is a relative complete evaluation method, it does not consider the interaction and interdependence among variables in the system. Furthermore, variables, such as reputation, are difficult to quantify.

Professor Thomas L. Saaty (1996) proposes the Analytic Network Process (ANP), which is designed to deal with the complexity in decision making processes. Considering the interdependence and interaction among variables, ANP assigns each variable a number between 1 and 9 and ranks bids based on the aggregated weighted numbers. All calculation work can be done by the "Super Decisions" software developed by professor Saaty. In the following part of this section, we will provide a comparison of these methods in choosing a winning bidder for a bridge construction and we will show that ANP method gives the best estimation and outperforms the other two methods.

To recognize the importance of introducing and encouraging ANP method in China, one should understand the methods being used in practice and what kind of pitfalls those methods are born with. First, in the lowest price method, a group of qualified bidders offer prices for the project and the offer with the lowest price wins. It does say in the prospectus that the prices should not be lower than the real expenses so as to avoid destructive competitions and downgraded quality. However to increase their ability to win the bid, weak bidding firms more than often come up with bids that are far lower than the estimation of real expenses. It is not a surprise to find out later that the finished products from the winning bidders chosen in this way often deviate from original expectations. The damages caused by lowest price method in bidding evaluation can be very significant. It not only crowds out "good" bidders in winning business by fair margins, but also brings economical catastrophe in crucial decisions. The synthesized method measures qualified bidders from several perspectives (e.g. the experience, the management of project, the quality control process, the reputation and the bidding price). A weighted score is assigned to each measuring variable and the aggregated number is compared among bidders. The one with the highest aggregated number will win. Although most of the important bridge constructions in China have applies this bidding evaluation method, it ignores the interdependence and interactions of selected variables and thus a suboptimal bidder might win the bid.

The last method, and the more important method, is ANP evaluation method. It not only considers the comprehensive capabilities of bidders but also introduces the interdependence of factors included. Table 16 presents the comparison of the three methods of bid evaluation that we described above.

Table 16 Comparison of three methods of bid evaluation

	Lowest Price	Synthesized Method	ANP
Factors	Bidding Prices	Price, Capacity, Project management, Quality Control, Experience and reputation	Price, Capacity, Project management, Quality Control, Experience and reputation
Methodology	Sorting by bidding prices	1. Give a score to each factor of the bidder 2. Calculate the weighted aggregated measure 3. Sort	1. Give a score to each factor of the bidder 2. Calculate the pair-wise comparison for each factor and calculate the weight 3. Calculate the interdependence among factors 4. Calculate the matrix 5. Rank
complexity	Simple	Complex	Most Complex
Winner-picking	The lowest price	Highest score	The Highest Rank
Reliability	Low	Middle	High

5.2.8.2 Decisive Factors

The important factors that are considered to pick a winner include: bidding price (**B_1**), construction capacity (**B_2**), project management (**B_3**), quality control (**B_4**), and experience and reputation (**B_5**). The weights of each factor can be assigned according to the Direction for the Construction of Expressways and Bridges. Once the highest weight is assigned to one of the most important factors (e.g. bidding prices), the weights for other variables can be calculated based on the pair wise comparisons. Table 17 presents the weights for each factor in our sample.

Table 17 Weights of main factors of bid evaluation

Factors of bid evaluation	Weight
Bidding price（B_1）	9
Construction capacity（B_2）	2.1
Project management（B_3）	1.5
Quality control（B_4）	1.2
Experience and reputation（B_5）	1.2

1. Bidding price（**B_1**）

Instead of offering a total price, bidding firms should give the detailed expenses for the project. We give an example of the possible expenses, and the weights are calculated as follow:

(1) The purchasing price should include all taxes (**C_1**);

(2) Prices for customized products (**C_2**);

(3) All the prices for the services listed on the prospectus (**C_3**);

(4) Price for the product test (**C_4**);

(5) Delivery costs (**C_5**).

To rank the prices offered, one could also compare them with the expected lowest prices. Closer the offer price is to the expected lowest prices, higher the score is given. Usually, prices that 10% lower than the expected lowest prices or 5% lower than the aggregated prices will have the highest score, which is 9 in our case, and prices higher than this offer price will get lower scores depending on the differences. The aggregated prices will be calculated as following:

$C = (A+B\times K)/2$

where：C－－ the expected lowest aggregated price;

A－－ the expected lowest price;

B− − the average bidding price;

K− − correction for low price competition. Usually it is 1 but can be 1.1 if destructive price competition exists.

When the project solicitator is not certain about the expected lowest price, he/she can assume A equals B and therefore, C will be equal to B when the K is one. For example, an automobile trade company receives a solicitation from a foreign company for the construction of a steel bridge and will advertise it in the domestic market. Since this trade company has no experience in the construction of steel bridge, it could not figure out the lowest possible price and will use the average price of the bidding price as a reference price. Table 18 shows the bidding prices from 5 bidders for the project.

Table 18 Five bidder prices

Unit：1,000 RMB

	C_1	C_2	C_3	C_4	C_5	Bidding Price
Bidder M_1	11,700	590	220	150	210	12, 8700
Bidder M_2	9,550	480	180	300	300	10,8100
Bidder M_3	8,400	420	150	300	230	9, 5000
Bidder M_4	7,900	390	150	300	260	9, 0000
Bidder M_5	9,300	470	150	300	300	10, 5200
Average	9,3700	4700	1700	2700	2600	105, 4000

2. Construction capacity（$\mathbf{B_2}$）

Scores will be given based on the assigned resources for the project ($\mathbf{C_6}$). The bid evaluation committee is supposed to give a visit to bidders' company.

3. Project management（$\mathbf{B_3}$）

Project management includes the management team, and the key technologies applied ($\mathbf{C_7}$). It is important to match the qualification and the number of the bidders' employees because to win the bid, some weak bidding firms "borrow" temporary employees or engineers from other companies.

4. Quality control（$\mathbf{B_4}$）

The score of quality control will be based on the bidding firms' quality control process and quality inspection technology ($\mathbf{C_8}$).

5. Experience and reputation（$\mathbf{B_5}$）

The reputation of a bidder will be measured by the quality of the similar projects conducted by the bidder within 5 years, whether they completed the projects on time ($\mathbf{C_9}$) and how they kept the contracts ($\mathbf{C_{10}}$). One needs to be very comfortable about the nature of the industry to give an accurate estimation on a bidder's reputation. For example, for steel framework, one might choose military related firms, state-owned large steel companies or joint ventures as the potential winners since they usually have ample resources, experienced managers with big projects, and most of all, they care more about their reputation.

Table 19 presents the scores of the five bidders in the main factors. The bidding price that is closest to the average price will have the highest score (9 in our case) and those higher or lower than this price will have lower scores. The lowest score is one.

Table 19 Scores of the five bidders in main factors

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Bidder M_1	3.03	4.64	6.12	5.00	9.00	8.81	7.65	9.00	8.55	9.00
Bidder M_2	8.01	8.90	9.00	9.00	6.00	7.02	8.31	9.00	7.35	8.55
Bidder M_3	7.15	8.50	8.00	9.00	8.33	5.23	4.65	9.00	6.83	2.25
Bidder M_4	3.54	5.21	8.00	9.00	7.33	4.86	6.78	5.62	3.91	1.20
Bidder M_5	9.00	9.00	8.00	9.00	6.00	6.32	6.59	8.00	6.07	5.11

5.2.8.3 Estimation Model

Figure 7 shows the interdependency network of the decisive factors based on ANP model.

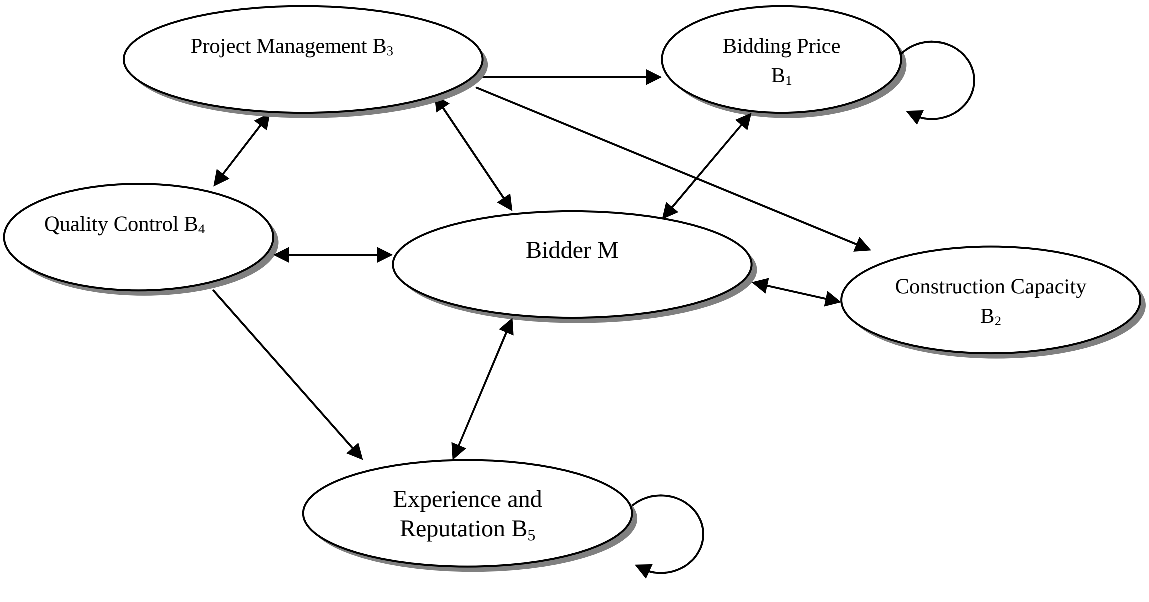

Figure 7. The ANP model for a bidder

5.2.8.4 Calculate the Eigenvector of Estimation Factors

All the calculation can be done by the software Super Decision. Table 20 presents the eigenvector of the five decisive factors and table 21 presents the eigenvectors of main factors for each bidder.

Table 20 Eigenvector of estimation factors

Decisive Factors	Weights（W）
Bidding Price（B_1）	0.6000
Construction Capacity（B_2）	0.1400
Project Management（B_3）	0.1000
Quality Control（B_4）	0.0800
Experience and Reputation（B_5）	0.0800

Table 21 Eigenvector of the main factors for each bidder

C_1	W	C_2	W	C_3	W	C_4	W	C_5	W
M_1	0.0972	M_1	0.1280	M_1	0.1564	M_1	0.1220	M_1	0.2455
M_2	0.2660	M_2	0.2455	M_2	0.2301	M_2	0.2195	M_2	0.1636
M_3	0.2317	M_3	0.2345	M_3	0.2045	M_3	0.2195	M_3	0.2272
M_4	0.1134	M_4	0.1437	M_4	0.2045	M_4	0.2195	M_4	0.2000
M_5	0.2917	M_5	0.2483	M_5	0.2045	M_5	0.2195	M_5	0.1637

C_6	W	C_7	W	C_8	W	C_9	W	C_{10}	W
M_1	0.2732	M_1	0.2251	M_1	0.2216	M_1	0.2614	M_1	0.3447
M_2	0.2177	M_2	0.2445	M_2	0.2216	M_2	0.2247	M_2	0.3274
M_3	0.1622	M_3	0.1368	M_3	0.2216	M_3	0.2088	M_3	0.0862
M_4	0.1507	M_4	0.1995	M_4	0.1383	M_4	0.1195	M_4	0.0460
M_5	0.1960	M_5	0.1939	M_5	0.1969	M_5	0.1856	M_5	0.1957

5.2.8.5 Calculate the Super-matrix

The super-matrix can be calculated by the software Super Decision also. Table 22, 23, and 24 presents the results for the unweighted super-matrix, the weighted super-matrix, and the limit super-matrix $\lim_{k\to\infty} W^k$ respectively.

Table 22 Unweighted super-matrix

	M_1	M_2	M_3	M_4	M_5	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
M_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.1280	0.1280	0.1564	0.1219	0.2455	0.2732	0.2251	0.2215	0.2613	0.3446
M_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.2455	0.2455	0.2300	0.2195	0.1636	0.2177	0.2445	0.2215	0.2247	0.3274
M_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.2344	0.2344	0.2045	0.2195	0.2272	0.1622	0.1368	0.2215	0.2088	0.0861
M_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.1437	0.1437	0.2045	0.2195	0.1999	0.1507	0.1995	0.1383	0.1195	0.0459
M_5	0.0000	0.0000	0.0000	0.0000	0.0000	0.2482	0.2482	0.2045	0.2195	0.1636	0.1960	0.1939	0.1969	0.1855	0.1957
C_1	0.2000	0.2000	0.2000	0.2000	0.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
C_2	0.2000	0.2000	0.2000	0.2000	0.2000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3	0.2000	0.2000	0.2000	0.2000	0.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4	0.2000	0.2000	0.2000	0.2000	0.2000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_5	0.2000	0.2000	0.2000	0.2000	0.2000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_6	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
C_7	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000
C_8	1.0000	1.0000	1.0000	1.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
C_9	0.5000	0.5000	0.5000	0.5000	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000
C_{10}	0.5000	0.5000	0.5000	0.5000	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	1.0000	0.0000

Table 23 Weighted super-matrix

	M_1	M_2	M_3	M_4	M_5	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
M_1	0.0000	0.0000	0.0000	0.0000	0.0000	0.0640	0.1280	0.0782	0.1219	0.2455	0.2732	0.0562	0.0737	0.1306	0.1723
M_2	0.0000	0.0000	0.0000	0.0000	0.0000	0.1227	0.2455	0.1150	0.2195	0.1636	0.2177	0.0611	0.0737	0.1123	0.1637
M_3	0.0000	0.0000	0.0000	0.0000	0.0000	0.1172	0.2344	0.1022	0.2195	0.2272	0.1622	0.0342	0.0737	0.1044	0.0430
M_4	0.0000	0.0000	0.0000	0.0000	0.0000	0.0718	0.1437	0.1022	0.2195	0.1999	0.1507	0.0498	0.0460	0.0597	0.0229
M_5	0.0000	0.0000	0.0000	0.0000	0.0000	0.1241	0.2482	0.1022	0.2195	0.1636	0.1960	0.0484	0.0655	0.0927	0.0978
C_1	0.1200	0.1200	0.1200	0.1200	0.1200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2500	0.0000	0.0000	0.0000
C_2	0.1200	0.1200	0.1200	0.1200	0.1200	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_3	0.1200	0.1200	0.1200	0.1200	0.1200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_4	0.1200	0.1200	0.1200	0.1200	0.1200	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_5	0.1200	0.1200	0.1200	0.1200	0.1200	0.0000	0.0000	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C_6	0.1400	0.1400	0.1400	0.1400	0.1400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2500	0.0000	0.0000	0.0000
C_7	0.1000	0.1000	0.1000	0.1000	0.1000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3584	0.0000	0.0000
C_8	0.0800	0.0800	0.0800	0.0800	0.0800	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2500	0.0000	0.0000	0.0000
C_9	0.0400	0.0400	0.0400	0.0400	0.0400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.5000
C_{10}	0.0400	0.0400	0.0400	0.0400	0.0400	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.3088	0.5000	0.0000

Table 24 Limit super-matrix

	M_1	M_2	M_3	M_4	M_5	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
M_1	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834	0.0834
M_2	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923	0.0923
M_3	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829	0.0829
M_4	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665	0.0665
M_5	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851	0.0851
C_1	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637	0.0637
C_2	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811	0.0811
C_3	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492
C_4	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492	0.0492
C_5	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738	0.0738
C_6	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719	0.0719
C_7	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580	0.0580
C_8	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473	0.0473
C_9	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425	0.0425
C_{10}	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523	0.0523

5.2.8.6 Ranking

Figure 8 shows the aggregated score for each bidder. Bidder M_2 has the highest score and becomes the winning bidder by using the ANP estimation method.

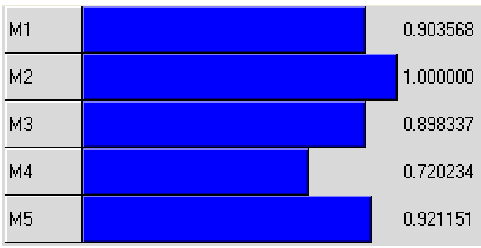

Figure 8. Synthesized overall priorities

5.2.8.7 Compare the Three Evaluation Methods

Table 25 shows the winning bidder of the three methods respectively. The three evaluation methods that we discussed above result in three different winning bidders. As we know that the lowest price method is the least reliable one and usually the winner from the lowest price method will sacrifice the quality of the product promised to get the project done. The winner from the synthesized method is bidder M4 and it does offer a price that is 290,000 RMB lower than bidder M2 does. But considering the interaction among factors, ANP method chooses bidder M_2 instead of M_5.

Table 25 Comparison of the results of the three evaluation methods

	Lowest Price Method	Synthesized Method	AN Method
Winner	M_4	M_5	M_2

5.3 Conclusion

The development of the construction of highways and bridges in China has been dramatic in the last two decades and it is still growing. With the increased complexity and the increased competition since China has entered WTO, it is more crucial than ever for decision makers to apply a reliable and reasonable evaluation method when pick winning bidders. We show that ANP method is an appropriate and accurate one.

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