STUDIES ON SYNTHETIC EVALUATION OF SCIENTIFIC RESEARCH OUTCOMES

By Zheng Min, Li Changshun, Zhou Qingwen,
Chen Guangyi, Li Yamin, Cheng Gang, Qiu Xuxin,
(Hebei Agricultural University, China)

ABSTRACT

In this paper, the application of Analytic Hierarchy Process (A H P) to synthetic evaluation of scientific research outcomes were studied. The outcomes were divided into four types: A---- new technology and new products; D---- soft sciences; G---- basic theory and Q---- extension and popularization. The four hierarchy models for each type and twenty-one judge matrices were constructed on the basis of expert consultation. By solving the matrices to find the eigenvectors, the importance weights of evaluation indexes were obtained, and the evaluation forms were also designed. Thus, a new method for deciding the awards of science and technology development was suggested. Its application showed that the method gave satisfactory results.

At present time, science and technology develop rapidly, and outcomes of scientific researches increase with each passing day. It is a important task for science and technology managerial personnel to improve the level of management. This study on " The synthetic evaluation of scientific research outcomes" includes: (1) Which factors and how these factors make up the outcomes of scientific researches? (2) Which indexes are taken into account by scientific research management departments of different levels when deciding on the awards of science and technology development? And what is the relationship between the indexes and the make-up factors of research outcomes? (3) Develop a new method for deciding on awards of science and technology development, which is more reasonable and more practical.

I. The analytic hierarchy process (A H P) is main methodolcgical approach in mathematical basis in this study. AHP was established by professor T.L. Saaty, an American operations researcher, in 1973 and was introduced to China by his student H.GholamNezhad in 1982. Many applications of the AHP have proved that it is reasonable and practical for various purposes. Everything has its internal hierarchy, so does in people's thinking process. AHP is a project of making decision according to object's herarchy and people's thinking process. Firstly the hierarchy model should be constructed and then be evaluated by experts. Then the weight numbers of correlative factors of the object can be achieved by quantifying evaluation results, constructing judgement matrices and solving the eigenvectors of each judgement matrix. Finally, the quantitatively synthetic evaluation, which provides scientific basis for decision, can be achieved according to the weight numbers.

The principle procedure of AHP is to construct a set of matrices equations according to the pairwise synthetic evaluation of several experts to the factors of a certain object and the decision can be made through calculating normalized weight numbers of each factor.

The procedures of AHP are as follows:

1. Investigate and study carefully the overall structure and each decision factor of an object to be evaluated, then construct a reasonable mathematical model of AHP.

2. Invite a group of experts who are typical representatives to evaluate the model, i.e. to do pairwise comparison of qualitative importance to each factor of each hierarchy and mark " " in the grade column. There are 1-9 scale which are classified into 5 grades. All these steps are the preparation for q quantitative analysis.

3. Construct a set of matrices.

4. Do local priorities and consistency check to each matrix.

5. Do global priority and consistency check. The eigenvector W of global priority is the normalized priority weight numbers of correlative factors of synthetic evaluation.

6. Invite another group of experts to evaluate concrete objects again in the same way. Multiplying the corresponding numbers of evaluations from each evaluation, the resulted sum of that multiplication is the final result of the evaluations.

II. Constructing mathematical model of AHP

According to their nature, the outcomes of scientific researches were divided into A, D, G, and Q type, the criterion hierarchy of the synthetic evaluation model was made up of several aspects of research outcomes or several aspects involved in the evaluation of research, and the index hierarchy was made up of several correlative factors which made up the research outcomes or the factors related to the synthetic evaluation. Thus four mathematical models of AHP were constructed.

1. Type A: research outcomes of new technology and new product

This type of outcomes can be directly put into production or applied to a certain production department to bring about the obvious economic benefit that can be calculated financially.

2. Type D: soft science research outcomes

This type of researches, such as regional planning, resource survey and allocation, management of scientific researches, compute programming, test or measurement method, planning policy and training of personnel, etc. are carried out for the reasons of policy decision or the goals of whole Society. These researches have obvious social benefit, but the economic benefit is hard to calculate financially.

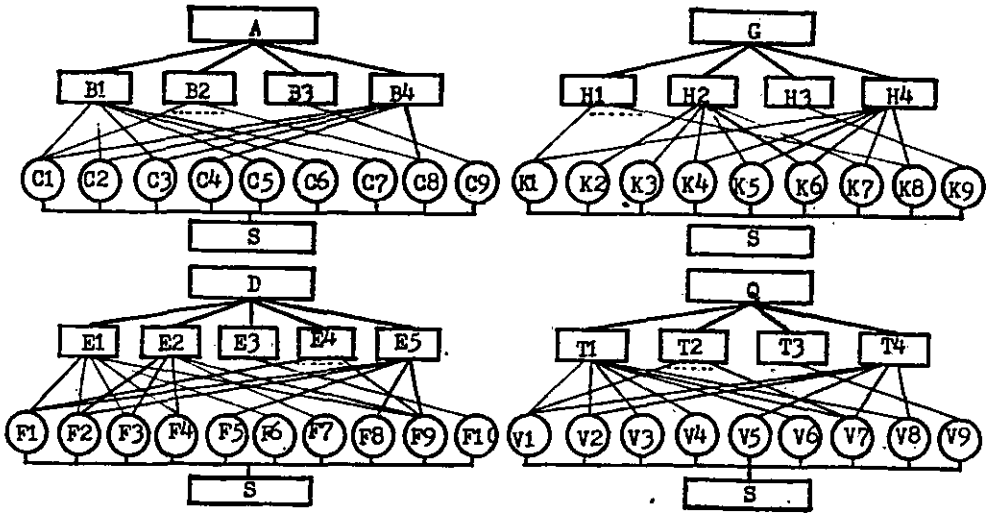
3. Type G: basic theory researches

This type of research outcomes is the one with knowledges and is signigicant to a certain subject. Still it has obvious social benefit.

4. Type Q: research on popularization and extension

This type of researches works with the extension and popularization of the research outcomes such as introducing advanced technology, improving the techniques in the light of special conditions, etc. This kind of outcomes should bring about significant economic benefits, or accelerate the development of national economics into certain extent

Fig.



S ---------- research to be evaluated
A, D, G, Q ---------- synthetic evaluation of research
B1, E1, H2, T1 ------- benefit
B2, E4, H1, T2 ------- level
C9, F10, K9, V9
B3, E3, H3, T3, ------ authoritativeness of the evaluation commission
C1, F9, V7, K7 ------- self-confidence of evaluation staff
C3, F2, K4, V2 ------- social benefit
C8, K8, V8, F8 -------scope and efficiency
C2, F1, V1 ---------- economic benefit
B4, E5, T4 ---------- scope
H4, F5, V5 ---------- complexity
C4, K1 ---------- level of knowledge
C5, K2 ---------- academic innovation
C6 ---------- technical level
E2 ---------- scientific decision, management modernization
F3 ---------- effect and influence
F4 ---------- significance
F6 ---------- innovation and level
F7 ---------- maturation and perfection
K5 ----------social effect
K6 ---------- academic significance
K3 ---------- academic level
V3 ---------- level of research to be extended (original level)
V6 ---------- level reached after the research being extended (new level)
V4 ---------- innovative skill

III. Evaluating the four mathematical models of AHP

Based on the four models, the evaluating forms corresponding with each model were designed. In order to get more accurate data, thirty experts were invited to give valuations. Among the experts, fifteen of them were the heads of scientific research department, science and technology commission of Hebei province, districts or cities. The others were scientists or technologists from provincial academy of agricultural sciences, academy of sciences, and universities. For the purpose of processing the evaluation data, the comparative signs ($>$, $=$, $<$) of the importance between correlative factors were used. According to the opinions of the most experts, the arithmetical means were calculated to make the valuations quantifying. All these procedures resulted in four synthetic tables of the data. (to be abbreviated)

IV. Constructing judgement matrix and doing local priorities in order to determine the priority of the factors in index hierarchy relatively to goal hierarchy. This is expressed on the right. Generally the local priority vectors $W = [W1, W2, \cdots, Wn]^T$ were achieved with radical root method:

A	B1	B2-------	Bn	W
B1	b11	b12------	b1n	W1
B2	b21	b22------	b2n	W2
Bn	bn1	bn2	bnn	Wn

a. Calculate the multiplication of all elements of each row:

$$Mi = \prod_{j=1}^{n} bij \quad ;$$

b. Calculate the nth root of Mi: $\overline{W} = \sqrt[n]{Mi}$;

c. Find eigenvectors: $Wi = \overline{W} / \sum_{j=1}^{n} \overline{W}$;

d. Find the maximum eigevalue of the matrix: $\lambda \max = \sum_{j=1}^{n} \frac{(AW)i}{nWi}$, where (AW)i respects the ith element of vector AW;

e. Calculate consistency index: $CI = \frac{\lambda max - n}{n-1}$.

f. The average random consistency indexs RI are:

1	2	3	4	5	6	7	8	9
0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

g. Find random consistency ratio: $CR = \frac{CI}{RI} < 0.10$

1. According to the above formulas, the mathematical model of synthetic evaluation on scientific research outcomes of type A is achieved as follows:

(1). Construct judgement matrix A-B and compare the relative importance among the criteria to the overall goal of synthetic evaluation. Below are the relative importance weights:

A	B1	B2	B3	B4	W
B1	1	2.86	4.68	4.15	0.53
B2	1/2.86	1	2.88	3.68	0.27
B3	1/4.68	1/2.88	1	1 /1.95	0.09
B4	1/4.15	1/3.68	1.95	1	0.12

$\lambda max = 4.15$, CI = 0.05 , RI = 0.90, CR = 0.05

(2). Construct judgement matrix B1-C and compare the relative importance among correlative indexes to benefit criterion. Below are the relative importance weights:

B1	C1	C2	C3	C5	C6	C7	W
C1	1	1/4.05	1/3.23	1/3.22	1/2.53	1/2.78	0.05
C2	4.05	1	3.38	3.34	2.78	2.77	0.36
C3	3.23	1/3.38	1	1/2.55	1/2.48	1/2.91	0.09
C5	3.22	1/3.35	2.55	1	2.88	1.48	0.21
C6	2.54	1/2.78	2.48	1/2.88	1	1/2.39	0.12
C7	2.78	1/2.27	2.91	1/1.49	2.39	1	0.19

$\lambda max = 6.39$, CI =0.08, RI = 1.24, CR= 0.06

(3). Construct judgement matrix B2-C and compare the relative importance among correlative indexes to level criterion. Below are the relative importance weights:

B2	C1	C2	C3	C4	C5	C6	C7	C8	W
C1	1	1/4.05	1/3.23	1/2.66	1/3.22	1/2.53	1/2.78	1/2.19	0.04
C2	4.05	1	3.38	3.66	3.35	2.78	2.27	4.01	0.29
C3	3.23	1/3.38	1	2.20	1/2.55	1/2.48	1/2.91	2.35	0.09
C4	2.66	1/3.66	1/2.20	1	1/2.81	1/2.37	1/3.03	1.85	0.07
C5	3.22	1/3.35	2.55	2.81	1	2.88	1/1.48	3.05	0.16
C6	2.54	1/2.78	2.48	2.37	1/2.88	1	1/2.39	2.99	0.11
C7	2.78	1/2.27	2.91	3.03	1.48	2.39	1	3.25	0.19
C8	2.19	1/4.01	1/2.35	1/1.85	1/3.05	1/2.99	1/3.25	1	0.05

$\lambda max = 8.52$, CI = 0.07, RI = 1.41, CR = 0.05

(4). Construct judgement matrix B4-C and compare the relative importance among correlative indexes to scope criterion. Below are the relative importance weights:

B4	C1	C2	C3	C4	C8	W
C1	1	1/4.05	1/3.23	1/2.66	1/2.19	0.07
C2	4.05	1	3.38	3.66	4.01	0.46
C3	3.23	1/3.38	1	2.2	2.34	0.22
C4	2.66	1/3.66	1/2.2	1	1.85	0.15
C8	2/19	1/4.01	1/2.35	1/1.85	1	0.11

$\lambda max = 5.19$, CI = 0.05 , RI = 1.12 , CR = 0.04

(5). Do global priority of hierarchy C and its consistency check. Construct judgement matrix and calculate according to the following formulas:

Weights of global priority: $W = \sum_{i=1}^{n} bi\ Ci$

Consistency check: $CI = \sum_{i=1}^{n} bi\ CI$; $RI = \sum_{i=1}^{n} bi\ RI$; $CR = CI / RI < 0.1$

C \ B	Bi	B2	B3	B4	global priority of hierarchy C.W
	0.53	0.27	0.09	0.12	
C1	0.05	0.04		0.07	0.05
C2	0.36	0.29		0.46	0.32
C3	0.08	0.09		0.22	0.09
C4		0.07		0.15	0.04
C5	0.21	0.16			0.15
C6	0.12	0.11			0.09
C7	0.19	0.19			0.15
C8		0.05		0.11	0.03
C9			1.00		0.09

CI = 0.07 , RI = 1.17 , CR = 0.06

2. The index weights for the research outcomes of type D, G, Q also can be achieved with the same method as above. (The calculation process is abbreviated.)

V. The results of the study

1. After doing consistency check for each matrix it was found that each CI was less than 0.1. This showed that all twenty-one matrices had satisfied consistency. The data used were reliable and the results were correct.

2. The importance weights of correlative factors of four type outcomes of scientific researches were obtained (confer the model):

Type A New Technology & New Product		Type D Soft Science Researches		Type G Basic Theory Researches		Type Q Researches or Extension	
C1	0.05	F1	0.05	K1	0.05	V1	0.34
C2	0.32	F2	0.19	K2	0.19	V2	0.19
C3	0.09	F3	0.14	K3	0.13	V3	0.06
C4	0.04	F4	0.12	K4	0.12	V4	0.10
C5	0.15	F5	0.02	K5	0.09	V5	0.04
C6	0.09	F6	0.22	K6	0.22	V6	0.08
C7	0.15	F7	0.11	K7	0.07	V7	0.05
C8	0.03	F8	0.02	K8	0.03	V8	0.07
C9	0.09	F9	0.06	K9	0.12	V9	0.08
		F10	0.08				

3. Using the above mentioned weights, four-type synthetic evaluation forms for

each type of scientific researches were designed (to be abbreviated). The different evaluation indexes were posed due to different types of researches and were given different weights according to the calculation. There were 1-9 scales which were divided into 5 grades. Scale 9 integrated the quantitative standard of the top awards in provincial level. Scale 7 integrated the quantitative standard of the top awards in district or city level. The quantitative judgement of a research, that were made by about mine experts in the same field by marking " " on the evaluation forms, were integrated by reexaminer. In order to avoid obviously subjective errors, the highest and the lowest evaluation numgers should be deleted and the mean of the evaluation numbers was calculated. This yielded the quantitative evaluation Ri of a certain evaluation index. Below is the weight synthesis of weight numgers of the correlative factors:

$$N = \sum_{i=1}^{n} Wij\ Rij$$, where Wij, Rij are the initial weight numbers and quantitative evaluation of each index; and N is the total score.

4. We have denigned the computer programme for deciding on awards of science and technology development. The discs are available for those institutes in where a lot of research outcomes are being evaluated. Through data processing, the computer can list the classified priorities of four-type researches and the priority of all researches. It can also analyse quantitatively the evaluation quality of evaluation staff.

VI. Discussion

1. To evaluate the outcomes of scientific researches more reasonably and pricisely, various mathematical analysis mathods have been applied and have made the qualitative judgement quantifying, obtaining the synthetic and quantitative evaluation. However, how to choose initial data correctly and how to avoid the influences from the valuator's subject projudice are still remained to be studied and perfected.

2. The integration of experts' evaluation and the decision from the administrative levels is the core of the synthetic evaluation suggested in this paper. In the course of the evaluation, what need the valuators to do is only to mark "✓" on the forms qulitatively according to their own judgement. Then the reexaminer will make the evaluation quantifying and get the priority of every research outcomes. Based on this priority, the management department or evaluation commission can easily decides the outcomes awarded and their prize grades.

3. In this study , the research outcomes were divided into A, D, G, and Q type and the hierarchy model for each type was designed. Based on the thirty experts' evaluation, the index weights for each type were noted for their exactness. The evaluation forms were simple, clear, exact and suitable for deciding on the awards. Besides, two indexes, authoritativeness of evaluation commission and self-confidence of the valuators were also involved into the overall make- up factors of the synthetic evaluation, although they were not the make-up factors of research outcomes. The evaluation forms we designed have following charactors:

(1). The evaluation is highly exact, because the forms are designed according to different types of research outcomes.

(2). The indexes are clear, concrete and highly quantitative. Still thdy are easily controlled by valuators.

(3). On the forms we set scale 9 as the quantitative index according to the top award criteria of provincial levle and scale 7 according to the top award criteria of district or city level. We synthesize all the evaluation criteria of provincial district and city levels in one form. So the forms are more practical and suitable for wide ranges.

(4). The results of our evaluation mathod are priorities and the total score which reflect the quality of the research outcomes. So this method can be applied in wide ranges.

(5). In the system of microcomputer evaluation, we have designed the programme of evaluation exactness of expert-group and evaluation exactness of expert. Therefore, both qualities of the research outcomes and the evaluatior quality of experts are evaluated simultaneously. That is helpful to avoid subject factors from valuators and to improve evaluation effectiveness.

4. Nowadays the trend of evaluation on scientific research outcomes is quantitative indexes, although methods and indexes used are different. And the evaluation forms are designed in setting several indexes, giving a set of weight numbers and synthesizing evaluation quantitatively. That is not only the trend but also the advanced level of science and technology management.

REFERENCES

1. HE. J . S .(1985). Inquiry on the synthetic evaluatior of scientific research by AHP . Theory and Practice of System Engineering 5 (1): 33--38. (In Chinese)

2. LIU . B . (1984). Analysis hierarchy process -----the mean of planning and decision. System Engineering 2 (2): 22--30. (In Chinese)

3. Saaty . T . L . (1980). The Analytic Hierarchy Process. MCGRAW-HILL INTERNATIONAL BOOK COMPANY.

4. ZHAO . H . C . (1986). Analysis hierarchy process. Science publishing house (In Chinese)

5. ZHEN . M . (1987). Study on the distribution of scientific research finance by AHP. Journal of Hebei Agricultural University 10 (4): 106-113. (In Chinese)