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MODEL AND APPLICATION OF FUZZY CONTROL SCIENTIFIC AND TECHNOLOGICAL EVALUATION

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Abstract. *Accurate, complete evaluation of scientific and technological information is an endeavor absolutely vital to scientific and technological advancement. Existing evaluation models, however, are not sufficiently comprehensive in that they do not combine qualitative and quantitative indicators. This study combined the fuzzy comprehensive evaluation model and fuzzy control model to create a novel method of science and technology evaluation, in which qualitative variables form an evaluation index that can be understood from various angles.*

Keywords: Science and technology evaluation, Fuzzy comprehensive, Fuzzy control

1. Introduction.

1.1. Background.

Science and technology are crucial components of social development, economic development, and enhancement of the human environment. Science and technology evaluation is an objective system which provides meaning and value to science and technology. Evaluation, conducted primarily by relevant experts, is a research endeavor which concerns the future, forecasted value of a project, leaving many study aspects unable to be successfully converted into quantitative indicators for analysis. Science and technology evaluation is based on inherent characteristics, and thus indicators/evaluation criteria must be chosen according to the most accurate possible information before being applied in a real-world, social or economic environment. The essential meaning of a research project, as well as its social and the economic value, must be thoroughly understood to measure science and technology activity accurately and comprehensively. Science and technology evaluation is affected by many subjective factors, so its practical effect and influence on end results cannot be measured by a simple number; fuzzy technology, which integrates qualitative and quantitative variables into one complete evaluation model, has been utilized successfully by previous researchers where precise, mathematical models cannot be established. This study used the fuzzy control method to build a science and technology evaluation method.

Fuzzy control was proposed in a doctoral thesis in the mid-1970s (Mamdani, 1974) for controlling processes, catalyzing a novel research area – the application of fuzzy control theory. Today, fuzzy control theory has been employed in systems engineering, psychology, biology, economics, medicine, and many other fields, offering valuable contributions that would otherwise not be possible without precise, mathematical models.

Figure 1 shows that the fuzzy control model can be divided into three main components.

(1) Fuzzy input stages, in which fuzzy comprehension is used to change digital input into fuzzy input.

(2) Establishment of fuzzy control rules, which builds a fuzzy relationship between fuzzy input and fuzzy output.

(3) Fuzzy output, which is the output of the final evaluation.

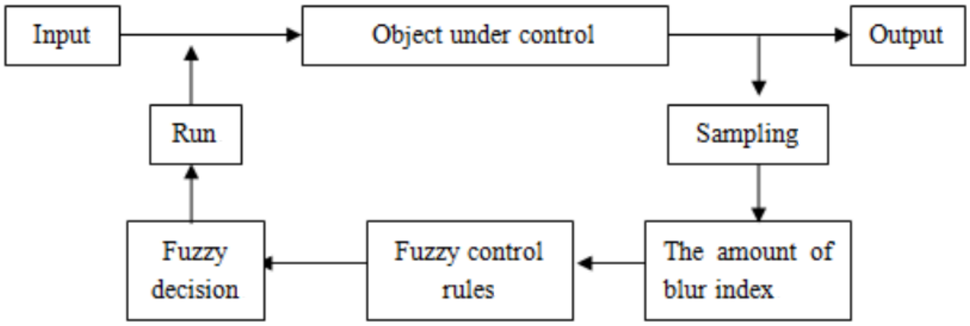

FIGURE 1. Schematic of fuzzy control

1.2. **Literature review.**

1.2.1. *Scientific and technology evaluation.* Science and technology evaluation, which has been investigated at length by many researchers and developers, has important implications as far as the degree and quality of advancements in science and technology are concerned. In a previous study, Zhou et al. [1] used multi-attribute decision-making to evaluate national scientific and technological infrastructure. Li [2] evaluated Chinese scientific and technological competitiveness using the super-efficiency DEA method. A novel method of objective weight analysis was tested in a study by Li and Yu [3]. Zhang and Hao [4] applied entropy theory to science and technology evaluation, and Xu [5] explored government investment in science and technology evaluation with the gray correlation analysis method. Recently, the amount and subject range of studies regarding science and technology evaluation have increased, but the majority of the proposed evaluation models were made without qualitative variables – for this reason, evaluated objects did not sufficiently accurately reflect reality. Fuzzy theory, as demonstrated in the present study, allows qualitative and quantitative variables to be examined in one model simultaneously to ensure comprehensiveness and objectivity.

1.2.2. *Fuzzy theory.* Fuzzy theory was first applied in the engineering field. As research continued, its applicability widened to include medical, military, and management fields, in which mathematical models were not able to be established accurately. Liu et al. [6] used the fuzzy comprehensive evaluation model to study internal corporate control environments, for example. Fuzzy control theory was also applied to evaluating the risk of ammunition accidents in a study by Qin et al. [7]. Downhole flow control devices applied in sandstone reservoirs were evaluated by Fang et al. [8] using fuzzy comprehensive evaluation. A reliable spectrum sensing and allocation model was built by Zhang et al. [9] using the fuzzy comprehensive evaluation method. Khan and Sadiq [10] applied fuzzy comprehensive evaluation to monitoring air pollution. Wang et al. [11] used the fuzzy comprehensive model to evaluate flood risk for bridges. Customer importance level was defined using the fuzzy comprehensive evaluation method by Guo et al. [12], and fuzzy control theory was applied to monitoring a network control system by Mendez-Monroy and Benitez-Perez [13]. Basically, fuzzy theory has been explored from a wide variety of perspectives, and applied successfully within many disparate research areas.

1.2.3. *Fuzzy theory combination in science and technology evaluation.* Scholars have also applied fuzzy theory to the study of science and technology evaluation. Chen and Ma [14] used the fuzzy comprehensive evaluation model to evaluate scientific and technological innovation capability, for example. Science and technology was evaluated by Zhang et al. [15] using maximum deviation and fuzzy comprehensive models. Chen et al. [16] applied fuzzy theory to evaluating science and technology resources. Compared to other methods, fuzzy theory applies both qualitative and quantitative variables simultaneously, allowing a combination of objective and subjective factors that cannot be measured numerically. Fuzzy comprehension combined with fuzzy control can form a science and technology evaluation system which takes account of different angles, stages, and indicators of quality. Fuzzy evaluation results are thus a much more comprehensive reflection of developments in science and technology.

Existing evaluation models [1-5,14-16] generally lack integrity, in that they do not typically combine qualitative variables with quantitative variables. The evaluation of a project under said models does not accurately reflect actual situations, which have widely varied angles and stages. In this study, the fuzzy comprehensive model and fuzzy control model are combined to create a novel science and technology evaluation model that is more complete, accurate, comprehensive, and flexible than pre-existing models.

2. The Establishment of Evaluating Model for Science and Technology.

2.1. Science and technology evaluation index set. In this study, the science and technology evaluation model was established based on regional scientific and technological development, drawing from international authority, high-frequency indicators, and relevant research literature to ensure the evaluation index was comprehensive, complete, and comparable [17-21]. The fuzzy comprehensive method and fuzzy control method were combined to evaluate scientific and technological development from two aspects.

(1) Output and input of science and technology indicators. Overall output and input of science and technology are not only represented by high-frequency indicators of international authority principles, but also directly reflect the strength of the indicators.

(2) Set of science and technology for the economic and social impact indicators. The ultimate goal of science and technology is to promote economic and social development and improve the human condition. Criteria must therefore define the economic and societal impact, specifically, of science and technology.

The evaluation index system utilized in this study is shown in Table 1.

Table 1. Science and technology evaluation index system

No.	Level indicators	Secondary indicators
1	Output of science and technology	Technology market turnover (Hundred million yuan)
2		number of patents
3		High-tech product exports (Hundred million Dollar)
4		High-tech industry output/industrial output (%)
5		fiscal policy support for innovation
6	Input of science and technology	R&D expenditure (Ten thousand yuan)
7		R&D expenditure/GDP (%)
8		Local Financial Allocation proportion accounted for fiscal expenditure (%)
9		R&D personnel per million full-time equivalent scientists (Person-years)
10		Scientists, engineers per million people in proportion (Millionth)
11	Science and technology for the economic and social impact	Labor productivity (Person-yuan)
12		The contribution rate of technological progress
13		Every ten thousand yuan overall GDP energy consumption (Tons of coal)
14		Comprehensive utilization rate of industrial solid waste (%)
15		Dependence on foreign technology

2.2. **Fuzzy comprehensive evaluation model.**

(1) Identify target set of science and technology evaluation factors.

Assume the science and technology evaluation factors set is **P**, which is divided into n subsets so that $P = P_1 \cap P_2 \cap P_3 \ldots \cap P_n$, and for any $i \neq j$, $i, j = 1, 2, 3, \ldots, n$, and $P_i \cap P_j = \Phi$. This forms the first layer of the evaluation factors $P_n = [P_1 \quad P_2 \quad P_3 \quad \cdots \quad P_n]$. Next, set the first k layer of evaluation factors as $P_K = [P_{k,1} \quad P_{k,2} \quad P_{k,3} \quad \cdots \quad P_{k,n}]$, where n is the number of evaluations.

(2) Quantify science and technology index values.

The Analytic Hierarchy Process (AHP), first proposed in the 1980s by T. L. Saaty, was utilized to determine the weight of the heavy index layer. First, a hierarchy system was built based on the relationship between system factors; second, indexes of each level were compared pair-wisely based on expert consultation to obtain judgment matrix $R = (r_{ij})$. The elements of each layer with respect to the weights of layer criteria were deduced according to their maximum eigenvalues and eigenvectors, obtained from the matrix described above. W_i is the weight of index, so index level indicators weights are $W_i = [W_{i1} \quad W_{i2} \quad W_{i3} \quad \cdots \quad W_{in}]$, where W_{in} is the weight of V_{in} on V, and $W_{i1} + W_{i2} + W_{i3} + \cdots + W_{in} = 1$.

(3) Divide review ratings.

Let **Z** denote the review ratings, i.e., $Z = [Z_1 \ Z_2 \ Z_3 \ \cdots \ Z_m]$, and m denote the number of evaluation results. Fuzzy evaluation level cannot be applied directly, so it is given different values based on quantitative assessment of needs.

(4) Establish fuzzy evaluation matrix.

A fuzzy evaluation matrix was established to build an evaluation index; the study object in this case was quartzite (measured in liters). The degree r_{ij} of P_{ij} belongs to where comment t was obtained (by expert evaluation or in-field survey). The resultant fuzzy judgment decision matrix is as follows:

$$R_i = \begin{bmatrix} r_{1,1} & r_{1,2} & r_{1,3} & \cdots & r_{1,n} \\ r_{2,1} & r_{2,2} & r_{2,3} & \cdots & r_{2,n} \\ \vdots & & \ddots & & \vdots \\ r_{n,1} & r_{n,2} & r_{n,3} & \cdots & r_{n,n} \end{bmatrix}$$

where $i = 1, 2, 3, \ldots, n$; $j = 1, 2, 3, \ldots, n$; $0 \leq r_{ij} \leq 1$.

The judgment decision matrix involves the membership of evaluation indexes to different evaluation levels, where said membership was determined by qualitative and quantitative indicators calculated separately. Qualitative indicators were obtained by level metrics comments $Z = [Z_1 \ Z_2 \ Z_3 \ \cdots \ Z_m]$ = [better, good, fair, poor, worse] = [9, 7, 5, 3, 1]. If the index is in the middle of these evaluation levels, [10, 8, 6, 4, 2] can also be used. Quantitative indicators were divided into three categories to determine their value: partial small (the smaller, the better), partial large (the bigger, the better) and intermediate (moderate). The specific characteristics of the objective were compared with the three categories to determine appropriate membership functions. Membership functions can be determined by fuzzy statistical method or fuzzy distribution. The trapezoidal membership distribution formula is as follows.

For partial small indicators, half-down trapezoidal membership functions are used for quantification:

$$R = \begin{cases} 1 & f(x) \geq \min(f) \\ \frac{\max(f) - f(x)}{\min(f) - f(x)} & \min(f) \leq f(x) \leq \max(f) \\ 0 & f(x) \geq \max(f) \end{cases} \tag{1}$$

For partial large indicators, half-liter trapezoidal membership functions are used for quantification:

$$R = \begin{cases} 1 & f(x) \geq \min(f) \\ \frac{f(x)-\min(f)}{\min(f)-f(x)} & \min(f) \leq f(x) \leq \max(f) \\ 0 & f(x) \geq \max(f) \end{cases} \tag{2}$$

For the intermediate, half-liter trapezoidal fuzzy membership functions are used for quantification:

$$R = \begin{cases} 0 & \min(f) \leq f(x) \leq \max(f) \\ \frac{2(f(x)-\min(f))}{\min(f)-f(x)} & \max(f) \leq f(x) \leq \min(f) \\ \frac{2(\max(f)-f(x))}{f(x)-\min(f)} & f(x) \leq \max(f) \cap f(x) \geq \min(f) \end{cases} \tag{3}$$

where $f(x)$ are eigenvalues. $\max(f)$ represents the upper limit of the same index for all eigenvalues, and $\min(f)$ is the lower limit corresponding to the same index of all eigenvalues.

(5) Build fuzzy comprehensive evaluation.

The weight vector and membership functions are coupled in order to draw science and technology evaluation vector $H = W \cdot R = [h_1 \quad h_2 \quad h_3 \quad \cdots \quad h_n]$, which is then compared to the configurated rating to make the final evaluation. The complete fuzzy comprehensive evaluation model is thus:

$$B_i = \sum_{i,j=1}^{n} W_{i,j} \cdot f(P_{i,j}) Z^T$$

2.3. **Establishment of fuzzy control rules.** Fuzzy control rules are actually set of multiple condition statements. This is an important part of fuzzy control [22], representing the fuzzy relationship between input and output variables. In this study, the fuzzy control rule statement mode settings were as follows: evaluation levels [better, good, fair, poor, worse] = [A, B, C, D, E]. Due to space limitations, the following is not completely enumerated, but in short:

If A and A and A, then A;
If A and B and A, then A;
If A and B and B, then A;
If B and B and B, then B;
If B and A and A, then A;
. . . . . .
If E and E and E, then E;
Etc.

3. **Application of Science and Technology Evaluation Model.** The proposed method was applied to scientific and technological achievement data corresponding to 10 provinces in 2009. Relevant experts were invited to evaluate the data and indicators using the evaluation model described above. Due to space limitations, details of the process are presented below solely for Beijing.

First, the fuzzy comprehensive evaluation model was used to evaluate three index systems. During the evaluation process, qualitative variables received one of five evaluation ratings $Z = [Z_1 \quad Z_2 \quad Z_3 \quad \cdots \quad Z_m]$ = [better, good, fair, poor, worse] = [9, 7, 5, 3, 1]. If an index was in the middle of these evaluation levels, [10, 8, 6, 4, 2] could also be used. The specific process is detailed below.

Index systems were rated by the experts using the Delphi method, and index weights were determined with AHP. The final result was:

$$W_1 = [0.26 \quad 0.19 \quad 0.19 \quad 0.10 \quad 0.26]$$
$$W_2 = [0.30 \quad 0.22 \quad 0.22 \quad 0.13 \quad 0.13]$$
$$W_3 = [0.33 \quad 0.25 \quad 0.17 \quad 0.17 \quad 0.08]$$

The indicator systems were then scored by the experts using the level proportion method, based on experimentation. Statistical results were as follows:

$$R_1 = \begin{bmatrix} 0.3 & 0.4 & 0.2 & 0.1 & 0.0 \\ 0.4 & 0.3 & 0.2 & 0.5 & 0.0 \\ 0.1 & 0.2 & 0.2 & 0.5 & 0.0 \\ 0.0 & 0.1 & 0.2 & 0.4 & 0.3 \\ 0.2 & 0.6 & 0.2 & 0.0 & 0.0 \end{bmatrix} \quad R_2 = \begin{bmatrix} 0.3 & 0.3 & 0.2 & 0.2 & 0.0 \\ 0.1 & 0.1 & 0.4 & 0.4 & 0.0 \\ 0.0 & 0.2 & 0.1 & 0.6 & 0.1 \\ 0.0 & 0.3 & 0.4 & 0.3 & 0.0 \\ 0.2 & 0.1 & 0.3 & 0.4 & 0.0 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0.3 & 0.5 & 0.1 & 0.1 & 0.0 \\ 0.1 & 0.3 & 0.5 & 0.1 & 0.0 \\ 0.1 & 0.3 & 0.2 & 0.2 & 0.2 \\ 0.0 & 0.1 & 0.3 & 0.5 & 0.1 \\ 0.3 & 0.5 & 0.1 & 0.1 & 0.0 \end{bmatrix}$$

Membership coefficient vector $R = W_i \cdot R_i$ was then obtained, the membership matrix composition of which is as follows:

$$h_1 = [0.225 \quad 0.365 \quad 0.200 \quad 0.180 \quad 0.030]$$
$$h_2 = [0.138 \quad 0.208 \quad 0.261 \quad 0.371 \quad 0.022]$$
$$h_3 = [0.165 \quad 0.348 \quad 0.251 \quad 0.185 \quad 0.050]$$

Based on the data above, final results are:

$$B_1 = h_1 \cdot Z^T = [0.225 \quad 0.365 \quad 0.200 \quad 0.180 \quad 0.030] \cdot [9 \quad 7 \quad 5 \quad 3 \quad 1]^T = 6.150$$
$$B_2 = h_2 \cdot Z^T = [0.138 \quad 0.208 \quad 0.261 \quad 0.371 \quad 0.022] \cdot [9 \quad 7 \quad 5 \quad 3 \quad 1]^T = 5.138$$
$$B_3 = h_3 \cdot Z^T = [0.165 \quad 0.348 \quad 0.251 \quad 0.185 \quad 0.050] \cdot [9 \quad 7 \quad 5 \quad 3 \quad 1]^T = 5.781$$

Compared to evaluation rating [better, good, fair, poor, worse] = [A, B, C, D, E]:

$$B_1 = 6.150 = B, \; B_2 = 5.138 = C, \; B_3 = 5.781 = C.$$

Fuzzy control rules provide the result: if B and C and C, then C.

So, in 2009, Beijing's science and technology level was C – the average general level. Science and technology evaluation of other provinces was conducted using the same method. Results are shown in Table 2.

As shown in Table 2, the level of scientific and technological development in these 10 provinces is relatively low. Shanghai received the most favorable evaluation overall.

Table 2. Science and technology evaluation results of 10 provinces

	Beijing	Heilongjiang	Shanxi	Liaoning	Guangdong
Part 1	B	D	C	C	C
Part 2	C	C	C	C	C
Part 3	C	C	C	D	B
Result	C	D	C	D	C
	Jiangxi	Shanghai	Henan	Shandong	Shaanxi
Part 1	C	C	C	C	C
Part 2	C	B	C	C	C
Part 3	D	B	C	C	C
Result	D	B	C	C	C

Beijing performed better as far as input of science and technology is concerned than other areas, Shanghai performed best in impact of science and technology on economy and society, and Guangdong and Shanghai had the best output of science and technology.

From the above results, we can not only see the overall rating level, and but also can see it in different parts of the evaluation level. The existing scientific evaluation model [1-5,14-16], can only get holistic evaluation results. The positive result could imply the plan was good, but we could not notice the negative part; the poor result could imply the plan was bad, but we could not notice the advantages. The new model can be more comprehensive evaluation of the project, and it could not only be able to evaluate the overall status of the project, but also reflect the good parts and the improved part of the project. For a highly volatile or cyclical project, sub-period, sub-angle evaluation can be better, more comprehensive and more realistic evaluation of science and technology projects, while was the other models could not.

4. **Conclusions.** Accurate, effective science and technology evaluation is a crucial component of scientific and technological advancement. Scientific and technological evaluation systems change according to the specific object being evaluated, so each evaluation must be appropriately specialized. The fuzzy control evaluation model proposed in this study is a combination of the fuzzy comprehensive evaluation model and fuzzy control model, which can be calculated according to any index system. Evaluation can be conducted from many different angles in this manner, and thus better reflect real-world situations. Examples provided above do verify the feasibility of the proposed method to some extent, though there is much room for improvement in the future.

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REFERENCES

[1] Q. Zhou, L. He and Q. Hua, Evaluation system for the performance of national science and technology infrastructure platform's operation based on multi-attribute decision making, *Lecture Notes in Management Science*, pp.447-452, 2013.

[2] X. Li, Super-efficiency DEA-based evaluation on China's science and technology competitiveness, *Comprehensive Evaluation of Economy and Society with Statistical Science*, pp.618-623, 2009.

[3] L. Li and L. Yu, A new evaluation approach of science and technology to objective weighting weight giving based on data independence and data fluctuation (DIDF), *The 7th International Conference on System of Systems Engineering*, pp.662-667, 2012.

[4] R. Zhang and C. Hao, Evaluation of science and technology progress of coal enterprise based on entropy, *International Conference on Intelligent Human-Machine Systems and Cybernetics*, pp.153-156, 2012.

[5] N. Xu, Performance evaluation of local government science and technology investment based on gray relational analysis – As illustrated by province, *Social Science Methodology*, pp.410-413, 2009.

[6] F. Liu, R. Tang and Y. Song, Information fusion oriented comprehensive evaluation model on enterprises' internal control environment, *Asia-Pacific Conference on Information Processing*, vol.1, pp.32-34, 2009.

[7] X. Qin, W. Li and W. Guo, Research on the application of fuzzy control theory in ammunition accident risk evaluation, *ISTM/2009 the 8th International Symposium on Test and Measurement*, vols.1-6, pp.2336-2338, 2009.

[8] Q. Fang, H. Liu and Y. Duan, Fuzzy comprehensive evaluation of the suitability of downhole inflow control device in sandstone reservoir, *AASRI Procedia*, pp.299-306, 2012.

[9] G. Zhang, Y. Zhang and X. Liu, Using fuzzy comprehensive evaluation method to establish a credible spectrum sensing and allocation model, *Security and Communication Networks*, pp.1912-1920, 2014.
[10] F. I. Khan and R. Sadiq, Risk-based prioritization air pollution monitoring using fuzzy synthetic evaluation technique, *Environmental Monitoring and Assessment*, pp.261-283, 2005.
[11] H. Wang, C. Hu and J. Yu, Fuzzy comprehensive evaluation method on flood-control risk consequence assessment of bridge, *Advances in Intelligent and Soft Computing*, pp.669-676, 2012.
[12] C. Guo, Y. Liu and P. Tian, Fuzzy comprehensive evaluation method of the importance ratings of customers' requirements, *Advances in Intelligent and Soft Computing*, pp.361-373, 2010.
[13] P. Mendez-Monroy and H. Benitez-Perez, Supervisory fuzzy control for networked control systems, *ICIC Express Letters*, vol.3, no.2, pp.233-240, 2009.
[14] L. Chen and S. Ma, Research on the science and technology innovation ability of undergraduates based on the fuzzy evaluation approach, *Advances in Intelligent and Soft Comuting*, pp.505-512, 2009.
[15] S. Zhang, G. Chi and M. Zhang, The science and technology evaluation model and empirical study based on maximizing deviation and fuzzy comprehensive evaluation, *Comprehensive Evaluation of Economy Society with Statistical Science*, pp.46-52, 2009.
[16] C. Chen, N. Bi and X. Lan, The analysis on the allocation capability of science and technology resources based on fuzzy evaluation, *PRMIA International Conference on Management Innovation*, vols.1-2, pp.1063-1068, 2007.
[17] IMD, *IMD World Competitiveness Yearbook 2007*, IMD Press, Lausanne, 2007.
[18] OECD, *Main Science and Technology Indicators*, Paris, 2007.
[19] World Bank, *2008 World Development Indicators*, World Bank Press, Washington D.C, 2008.
[20] Hariolf Grupp, Mary Ellen Mogee indicators for national science and technology policy: How robust are composite indicators, *Research Policy*, vol.33, pp.1373-1384, 2004.
[21] S. Kobayashi and Okubo, Demand articulation, a key factor in the reconfiguration of the present Japanses science and technology system, *Science & Public Policy (SPP)*, vol.31, no.1, pp.55-67, 2004.
[22] T. Dereli and K. Altun, Technology evaluation through the use of interval type-2 fuzzy sets and systems, *Computers & Industrial Engineering*, vol.65, no.4, pp.624-633, 2014.