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Application of Group Analytical Hierarchy Process on E-commerce Performance Evaluation Considering Expert Weight

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Abstract

With the rising popularity of e-commerce, more and more enterprises begin to construct and adapt to e-commerce system. It is far more than a simple computer system. Currently, many experts and organizations have attempted to evaluate the e-commerce performance theoretically. However, there is a white space in the theory, in particular the theoretical system of e-commerce performance evaluation. Thus, this paper sets up an index system for e-commerce performance evaluation based on features of e-commerce enterprises and evaluation theories. It proposes a Group Analytical Hierarchy Process (GAHP) that is proved to work out well when evaluating the e-commerce performance.

Keywords: *E-commerce; Performance evaluation; Group Analytical Hierarchy Process (GAHP); Index system*

1. Introduction

E-commerce nowadays is gaining momentum. Profit-oriented and driven by the rapid development of the commercialized Internet, more and more enterprises are constructing their own e-commerce systems. Conventional management theories can no longer cope with fast changes. Many new problems need to be addressed at theoretical level and practical level. E-commerce performance evaluation is one of them.

As an important tool of learning and feedback, e-commerce performance evaluation enables the flow of the expected value of the evaluation or the evaluated value of leading e-commerce enterprises inward, so that enterprises can chart the correct direction of using e-commerce. From a long-term perspective, e-commerce performance evaluation can help enterprises better understand the commercial value of e-commerce and accumulate experience for further development. Thus, evaluation theory of e-commerce system is at the frontier of related researches. It facilitates the identification of the role that e-commerce plays in enterprises and of the features in different industries and enterprises.

However, according to the survey issued in 2005: 1.58% e-commerce enterprises failed to evaluate its e-commerce system. 2. Less than 10% were able to measure the return on investment. 3. Though network marketing-e-channel is a main customer contact point, traditional marketing modes (such as face-to-face sales, business partnership and sales

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through telephone) created as much as 95% of the total income 4. The existing e-commerce system is limited to the input and construction of information infrastructure. Less than 30% of enterprises start integrating e-commerce operation and analytic environment. This reveals two problems: one is that many enterprises lack comprehensive and scientific understanding about e-commerce; the other is the difficulty in measuring the value of e-commerce system. This paper identifies that this is due to a lack of an effective e-commerce performance evaluation.

E-commerce performance evaluation consists of three parts, namely, indexes of evaluation, the determination of weight of indexes and the evaluation approach. Domestically and abroad, Zhang [1], Xu [2], Sedera [3], Schubert [4] and some others have done empirical researches on information and e-commerce system. These pave the way for researches on e-commerce evaluation. However, the white space exists widely.

This paper first gives an overall introduction of relevant literatures and designs an index system for e-commerce performance evaluation. At last, it analyzes the application of Group Analytical Hierarchy Process (GAHP) on e-commerce performance evaluation considering expert weight.

2. Literature Review

Domestic and foreign researches on information system or e-commerce system are divided into two directions. One is the establishment of the index system. These studies such as by Zhang [1] and Xi [5] are featured by quantitative description but a lack of empirical researches. Some others such as by Xu [2] focus on evaluation approaches mainly based on mathematical algorithm. Foreign researches mainly focus on information system evaluation by empirical study, like Sedera [3] and Zhuang [6]'s research. There are also foreign researches involving evaluation approaches, such as by Stewart [7] and Schubert [4].

From the abovementioned situation, we can conclude that domestic researches emphasize on mathematical approaches but lack the test on reasonability and availability of the evaluation approach by real data. In comparison, foreign researches value more on empirical study, in particular the establishment of the index system. Few involve with evaluation approach.

In the research field of information system and e-commerce system, Technology Acceptance Model (TAM) [8], D&M model of information systems success [9], SERVQUAL [10] and other theory models can instruct on the selection of index of e-commerce evaluation. For examples, Schubert [4] uses TAM model in his EWAM (Extended Web Assessment Method) to improve the index system. Sedera [3] and Rai [11] apply D&M model of successful information systems to the study of evaluating information system. Pitt [12] and Kettinger [13] study the role of SERVQUAL in information system evaluation. Huang (2004) proposes his index system based on the index system for performance evaluation of domestic enterprises, Porter's value chain model and relevant researches [14]. He evaluates the e-commerce system from the view of the influence of e-commerce on enterprises and on their performance. In his study, e-commerce is defined as a kind of purchasing and selling activity that is carried out through Internet by enterprises. It involves with information sharing and trade via Internet between enterprises and suppliers and customers.

3. Index System for e-commerce Performance Evaluation

According to Chinese index system for enterprise performance evaluation [15], economic index, organization satisfaction and self-development capacity are measured as three secondary indexes for e-commerce performance evaluation. 17 tertiary indexes are determined and shown as in Table 1.

Economic index is mainly measured up by financial statement and performance statement in the form of increased revenue or decreased cost. It consists of core economic index and derivative index. Core economic index refers to direct revenue and cost produced by the system, such as construction cost (mainly the one-time construction cost), operational cost, economic earnings directly brought by e-commerce system, decreased cost in management and logistics as a result of exercising the system, *etc*. Derivative index refers to indirect revenue and cost, such as the revenue of other operation rather than e-commerce as a result of increased efficiency, increased market share, *etc*.

Organization satisfaction refers to how much individuals outside the enterprise, employees, management teams and other individuals or organizations inside the enterprise feel satisfied about the e-commerce system. Some indexes can be measured up by database involving the use of frequency and success rate of responses. Others can be acquired by surveys in the form of percentage statistics.

Self-development capacity refers to self-update ability and intelligence degree. It includes system quality, data quantity and how the system influences the development of the enterprise, all reflecting the potential of development and measured by data acquired in different period after operating the system.

As these indexes are distinguished from each other, they need to be nondimensionalized to be comparable. And measure up the effects based on polarity. Deng (2002) shows one of the approaches to nondimensionalization.

Table 1. Index System for e-commerce Performance Evaluation

Primary index	Secondary index	Tertiary index	Notes
E-commerce performance evaluation	Economic index	Development cost(Yuan)X1	Calculated by finance statistics
		Operational cost(Yuan)X2	
		Revenue growth(Yuan)X3	
		Lowered percentage of general and administration cost (%)X4	
		Increased market share (%) X5	
		Capital turnover (%)X6	
	Organization satisfaction	Customer retention rate (%)X7	By statistics
		Additional click-through rate (%)X8	By statistics
		Percentage of customers who are willing to use e-commerce (%)X9	By surveys and statistics
		Time of information processing (Hour) X10	By statistics
		Percentage of useful information (%)X11	By statistical and internal estimation
		Effectiveness of system links (%)X12	By statistical evaluation
	Self-development capacity	Information update rate (%)X13	By surveys
		Self-testing and self-repairing capability (%)X14	By statistical records
		Increased productivity of employees (%)X15	By statistical estimation
		Development cycle of value-added products(Day)X16	By statistics
		Growth rate of customized service (%)X17	By statistics

① For index of "maximum", the upper limit effect measurement is: $R_{ij}^{p} = \frac{E_{ij}^{p}}{\max_{i} E_{ij}^{p}}$

② For index of "minimum", the lower limit effect measurement is: $R_{ij}^{p} = \frac{\min_{i} E_{ij}^{p}}{E_{ij}^{p}}$

③ For index of "moderate", the upper limit effect measurement is: $R_{ij}^{p} = \frac{\min_{i}\{E_{ij}^{p}, E_{0}^{p}\}}{\max_{i}\{E_{ij}^{p}, E_{0}^{p}\}}$

Among it, $E_{0}^{p} = \frac{1}{n}\sum_{i=1}^{n} E_{ij}^{p}$, i refers to sample and j refers to index.

4. Application of GAHP on e-commerce Performance Evaluation

As indexes have different importance to the overall evaluation, the evaluation model needs to address the weight of each index. There are many ways to assign weight, such as Delphi [16], AHP [16], furry mathematical method [17], entropy method [16], variation coefficient method [18], KantiRary method [18], best comprehensive evaluation model ("Scatter degree method")[16], PC-LINMAP comprehensive method [19], *etc*. Besides that, there are other methods for preference aggregation of people, such as OWA operator [20], OWG operator [21], MA-OWA operator [21], *etc*.

The abovementioned methods fall into two categories: subjective weighing method and objective weighing method. Objective weighing method gets the weight from evaluation index of enterprises, which is not adaptive to this research. In comparison, subjective weighing method overlooks the expert weight that may lead to a fallacy. Thus, this paper intends to design a GAHP considering expert weight.

4.1. Introduction of AHP

AHP could date back to 1970s. In 1971, Sadi Taha once used AHP for the "Emergency plan"of the United States Department of Defense. In 1972, he applied it to distribution of power industry for National Science Foundation (NSF). In 1973, AHP was used to solve transportation problem for The Republic of the Sudan [22]. In 1977, Sadi delivered a speech entitled "Modeling of non-decision making--AHP" in the First Mathematical Contest in Modeling [23, 24]. AHP refers to disposing the complex multi-target to many sub targets or scales and into multiple indexes and layers. It then calculates the priority of each layer and the overall priority by fuzzy qualitative method so as to optimize the decision.

When using AHP to calculate the weight of the index system, the first thing to do is to construct a suitable layer for the structure. This structure model can divide the complicated problem into elements that are easy to understand. These elements will further be divided into several groups with different layers. Elements of the same layer dominant elements of a lower layer and are dominated by elements of a higher layer [25].

Usually these layers include the goal, the criterion and the alternatives. The evaluation model of AHP is shown in Figure 1.

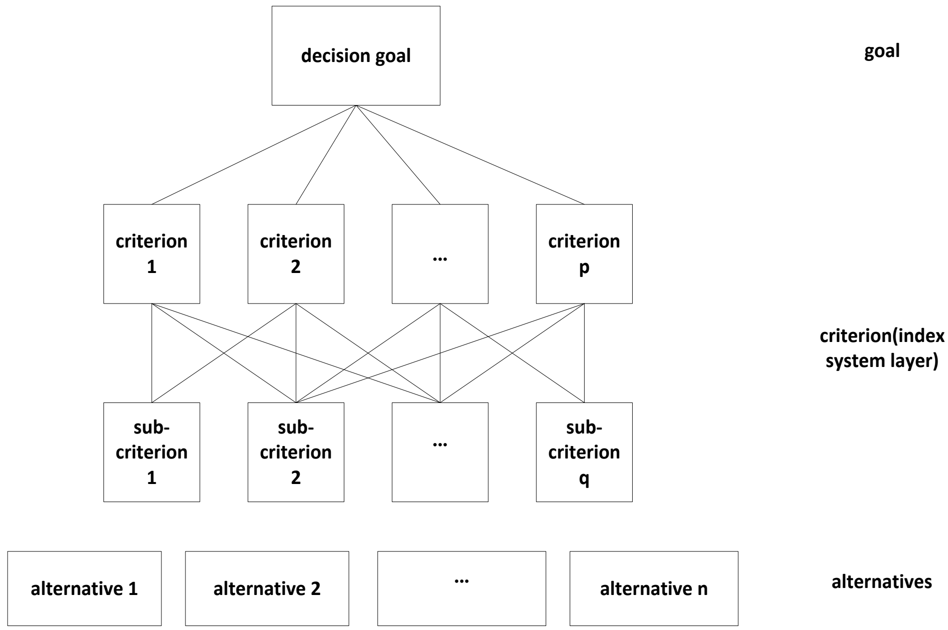

Figure 1. Normal AHP Model Structure

After constructing the layer model, we can construct comparison matrices. Rank them in each layer and test the consistency. Calculate AHP by the overall priority [26] and compare the weight of index in the alternatives.

4.2. Information Aggregation of GAHP

(1) Introduction of aggregation

AHP relies on experts to judge on elements and work out the matrix. However, the judgment matrix can be subjective. Thus, the solution is that decision makers should invite several experts to judge on the same model and work out the comprehensive aggregation to get the priority of weight [27]. Such aggregation falls into the category of individual efficacy aggregation.

Aggregation method of expert judgment on GAHP can generally be divided into two categories: The first is AJI (the aggregation of individual judgments), namely, several individual judgment matrices form a unified group judgment matrix. When the consistency of an individual judgment matrix is more than 0.1, it can be kicked out of the group matrix or be asked to do re-judgment. The second is the AIP (the aggregation of individual priorities). Evaluating the judgment matrix based on individual evaluating system doesn't favor the aggregation of judgment matrices for each layer. Here, we only pay attention to the priority result of each individual [28].

(2) Mathematical method for aggregation

Suppose $a_{ij}^{1}, a_{ij}^{2}, \cdots a_{ij}^{n}$ are n members to judge the importance between index i and index j. Based on previous researches, there are several mathematical methods for the aggregation of judgment matrices.

① Arithmetical average method(AMM)

The expression of AMM is: $(\sum_{k=1}^{n} a_{ij}^{k}) / n$ (1)

② Geometric average method(GMM)

The expression of GMM is: $(\prod_{k=1}^{n} a_{ij}^{k})^{1/n}$ (2)

③ weighted arithmetic mean method(WAMM)

The expression of WAMM is: $\sum_{k=1}^{n} \omega^{k} a_{ij}^{k}$ (ω^{k} is the weight of individual k) (3)

④Weighed geometric mean method(WGMM)

The expression of WGMM is: $\prod_{k=1}^{n} (a_{ij}^{k})^{\omega^{k}}$ (ω^{k} is the weight of individual k) (4)

The previous two of the four aggregation methods do not have the aggregation of expert weight. The rest two are proper for when the weight of each expert is different. Xu et al. (2000) [29] proves the consistency of WGMM. When CR is less than or equals to 0.1, then the judgment matrix through WGMM will live up to the standard of consistency.

(3) Expert weight

As a result of individual preference and different knowledge background, experts may disagree with the judgment [30]. That is to say the weight of each expert should not be equal. This matters much in GAHP.

The determination of expert weight can be through subjective weight, objective weight or a combination of the two.

① Subjective weight

Subjective weight methods include AHP method, Delphi method, etc. However, as experts are carefully selected by decision makers, it can be assumed that they have the same subjective weight [31].

② Objective weight

In GAHP, objective weight methods mainly rely on information contained in the judgment matrix given by experts. There are currently the followings.

I determine the weight according to the consistency

He (2003) [32] thinks that if a judgment matrix has a high consistency, it means that the ranking result is high in quality, accuracy and reliability. Thus, a judgment matrix with a higher consistency will influence the priority of vectors and vice versa.

II Determine the weight according to the discreteness of expert judgment

Wang *et al.*, (2004) [33] use the "Minimum variance" to determine the relative weight by comparing the scale and the optimal variance. Bai (2004) [34] introduces the relative membership degree to determine the weight of each expert.

III Determine the weight according to the similarity of experts' judgment

If two experts get similar judgment matrices, it is assumed that the priority of vectors is accurate and reliable. Thus, judgment matrix with higher similarity has great influence on the priority of vectors and vice versa. Thus, the principles for weight determination are: frequency, distance and clustering analysis.

4.3. The Application of GAHP Considering Expert Weight on e-commerce Performance Evaluation based on the Similarity of Judgment Matrices

(1) Selection of aggregation method

Consistency Rate (CR) of expert judgment matrix in the three-layer evaluation index system can be acquired by software called Yaahp. Out of convenience, we invite several experts to provide with judgment matrices of the equipment manufacturing industry and eliminate the improper results (if $CR>0.1$). In accordance with the evaluation index system designed by this paper, the judgment matrices made by experts can be aggregated. This paper chooses AIJ for aggregation and WGMM for mathematical method of aggregation since it addresses the expert weight and its advantages have been proved in Xu (2000), that is, when all judgment matrices are subject to the consistency test and when CR is less than or equals to 0.1, the judgment matrices through WGMM will be sure of passing the consistency test.

(2) Determine the expert weight

Given that those experts are masters from industry or excelled at management or economy, the subjective weight can be assumed as equal. So this paper will only focus on the objective weight rather than the subjective weight. For feasibility and simplicity concerns, this paper determines the objective expert weight according to the similarity of judgment matrices. The steps are shown below in Figure 2.

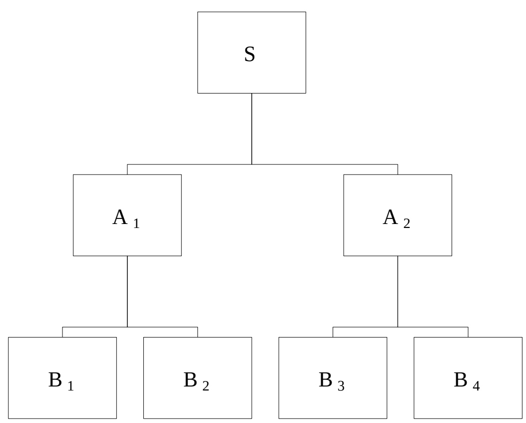

Figure 2. Assumed Evaluation Layer

Suppose the evaluation layers are as Figure 2, after applied to the consistency test, the judgment matrix of all layers of expert *i* is presented below:

Table 2. Judgment Matrix for the Goal(S)

Goal(S)	A_1	A_2
A_1	1	a_i
A_2	$1/a_i$	1

Table 3. Judgment Matrix for A_1 Layer

A1	B_1	B_2
B1	1	b_i
B2	$1/b_i$	1

Table 4. Judgment Matrix for A_2 Layer

A2	B_3	B_4
B_3	1	c_i
B_4	$1/c_i$	1

a_i, b_i, c_i are selected from 17 indexes. In this paper, the objective expert weight is determined according to their judgment matrices. So the indexes in the matrix are used to measure similarity. Therefore, as the number of the evaluation layer and indexes in each layer rises up, they bring some difficulties to determine the objective weight. So it is suggested to use part of the information in the judgment matrix as the representative for all.

As the judgment matrices made by experts are reciprocal matrices where the upper triangle and the lower triangle are reciprocal. So we only select the upper triangle while excluding the diagonal line to stand for all information so as to simplify the evaluation process.

Here we aggregate the effective information in the judgment matrix as in Table 2, Table 3 and Table 4 to construct the evaluation matrix considering expert weight. The result is shown in Table 5.

Table 5. Evaluation Matrix Considering Expert Weight

Expert	Index 1	Index 2	Index 3	Index 4
Expert 1	a_1	b_1	c_1	…
Expert 2	a_2	b_2	c_2	…
…	…	…	…	…
Expert n	a_n	b_n	c_n	…

Based on the evaluation matrix shown in Table 5, those with higher similarity win more weight. For sure, it needs to point out that for the judgment of the same index, it can't be that all are similar to each other nor none are similar. To solve this trouble, this paper assumes that for each index, those experts who have a closer judgment to the average judgment result can win more weight. Since each index is treated this way, we can get the objective weight of each expert for all indexes.

Based on such assumption, we can get also the average judgment of each index: $\overline{a}$, $\overline{b}$ and $\overline{c}$. Then we prescribe that experts whose judgment is close to the average wins more measure for this index. For index 1, the weight measure of expert i can be expressed by:

$$a_i^* = \frac{\min_n\{a_i, \overline{a}\}}{\max_n\{a_i, \overline{a}\}} \quad (0 \le a_i^* \le 1) \tag{5}$$

According to expression (5), the evaluation measure for index 1 of expert *i* is transformed to a number between 0-1. The closer it is to 1, the closer his judgment to the average. Here we have obtained the judgment matrix considering expert weight and changed measure, as is in Table 6.

Table 6. Judgment Matrix Considering Expert Weight and Changed Measure

Expert	Index 1	Index 2	Index 3	Index 4
Expert 1	a_1^*	b_1^*	c_1^*	…
Expert 2	a_2^*	b_2^*	c_2^*	…
…	…	…	…	…
Expert n	a_n^*	b_n^*	c_n^*	…

Table 6 explains that larger the scale is, the closer to the average judgment for this index. So, we add up all judgment scales of each expert. The larger the sum is, the more weight this expert should win. Then we can get the judgment matrix containing comprehensive indexes of experts, as is shown in Table 7.

Table 7. Judgment Matrix Containing Comprehensive Index of Experts

Expert	Comprehensive index
Expert 1	$I_1 = a_1^* + b_1^* + c_1^*$
Expert 2	$I_2 = a_2^* + b_2^* + c_2^*$
…	…
Expert n	$I_n = a_n^* + b_n^* + c_n^*$

We normalize the comprehensive index and here comes the objective expert weight. The expression of normalization is:

$$\omega_i = \frac{I_i}{\sum_{i=1}^{n} I_i} \tag{6}$$

The expert weight is shown in Table 8.

Table 8. Expert Weight

Expert	Expert weight
Expert 1	ω_1
Expert 2	ω_2
…	…
Expert n	ω_n

It accords with $\sum_{i=1}^{n} \omega_i = 1$. Then we use WGMM to aggregate the judgment matrices of experts to get the final one, which is proved to pass the consistency test. With this final judgment matrix, we can get the weight of each economic index. With index weight and the index value after nondimensionalization, it is easy to score the performance of enterprises with e-commerce. A rank will be available by comprehensive scores.

The AHP that considers expert weight than that which doesn't is more advanced in that the aggregated matrix is more consistent. Suppose the judgment matrices of five experts are:

$$A^1=\begin{bmatrix}1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{3} & \frac{1}{3} & \frac{1}{3}\\ 3 & 1 & 1 & 1 & 1 & 3\\ 3 & 1 & 1 & 1 & 1 & 3\\ 3 & 1 & 1 & 1 & 1 & 3\\ 3 & 1 & 1 & 1 & 1 & 3\\ 3 & \frac{1}{3} & \frac{1}{3} & \frac{1}{3} & \frac{1}{3} & 1\end{bmatrix},\quad A^2=\begin{bmatrix}1 & \frac{1}{5} & \frac{1}{5} & \frac{1}{5} & \frac{1}{7} & 1\\ 5 & 1 & \frac{1}{3} & 3 & \frac{1}{5} & 5\\ 5 & 3 & 1 & 1 & 1 & 5\\ 5 & \frac{1}{3} & 1 & 1 & \frac{1}{3} & 3\\ 7 & 5 & 1 & 3 & 1 & 5\\ 1 & \frac{1}{5} & \frac{1}{5} & \frac{1}{3} & \frac{1}{5} & 1\end{bmatrix},\quad A^3=\begin{bmatrix}1 & 3 & \frac{1}{3} & 3 & 5 & 7\\ \frac{1}{3} & 1 & 7 & 7 & 5 & 3\\ 3 & \frac{1}{7} & 1 & 3 & 3 & 5\\ \frac{1}{3} & \frac{1}{7} & \frac{1}{3} & 1 & 7 & 7\\ \frac{1}{5} & \frac{1}{5} & \frac{1}{3} & \frac{1}{7} & 1 & 3\\ \frac{1}{7} & \frac{1}{3} & \frac{1}{5} & \frac{1}{7} & \frac{1}{3} & 1\end{bmatrix},$$

$$A^4=\begin{bmatrix}1 & \frac{1}{3} & \frac{1}{3} & \frac{1}{5} & \frac{1}{5} & 3\\ 3 & 1 & 1 & \frac{1}{3} & \frac{1}{3} & 3\\ 3 & 1 & 1 & 1 & \frac{1}{3} & \frac{1}{3}\\ 5 & 3 & 1 & 1 & 3 & 1\\ 5 & 3 & 3 & \frac{1}{3} & 1 & 7\\ \frac{1}{3} & \frac{1}{3} & 3 & 1 & \frac{1}{7} & 1\end{bmatrix},\quad A^5=\begin{bmatrix}1 & 1 & \frac{1}{5} & \frac{1}{3} & 1 & 1\\ 1 & 1 & \frac{1}{5} & \frac{1}{5} & \frac{1}{3} & 1\\ 5 & 5 & 1 & 3 & 5 & 3\\ 3 & 5 & \frac{1}{3} & 1 & 1 & 1\\ 1 & 3 & \frac{1}{5} & 1 & 1 & 1\\ 1 & 1 & \frac{1}{3} & 1 & 1 & 1\end{bmatrix}.$$

Through the discussed method, we can get the weight of each expert: 0.230991, 0.192927, 0.202809, 0.185903, 0.18737. The calculated CR_1 of the aggregated judgment matrix through WGMM is CR_1=0.0009577. The calculated CR_1 of the judgment matrix without considering expert weight and through GMM is CR_2=0.001019. It is obvious that CR_1<CR, which means that the method proposed in this paper is more accurate and reliable with a higher consistency.

5. Conclusion

This paper designs an index system for e-commerce performance evaluation and applies to it Group Analytical Hierarchy Process considering expert weight. It proves to be more accurate than traditional GAHP and makes up for the loop-holes in existing domestic and foreign researches on e-commerce performance evaluation.

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