

Research Article

Research on Efficiency of Animation Enterprises Based on Two-Stage DEA Network System Model of Sharing Input Resources

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This research constructs a two-stage DEA network system model of shared input resources to evaluate the efficiency of animation companies: the first-stage efficiency to reflect the production quantity and the second-stage efficiency to reflect the production quality of animation products, where the quality of animation products is judged based on the market recognition of the animation products. The overall efficiency in the research model is used to describe the development of animation enterprises. According to the result, it is concluded that the overall efficiency of the surveyed animation companies and the efficiency of each sub-stage have shown an upward trend, which is in line with the growth of the company's development.

1. Introduction

1.1. The Development Status of the Animation Industry. In the context of economic globalization, the world economy is developing rapidly, material wealth has been accumulated, traditional economic growth has encountered bottlenecks, and the spiritual and cultural needs of people who have solved the problem of food and clothing are increasing day by day [1]. More countries and governments pay more attention to the development and layout of cultural industries and propose to develop cultural industries into pillar industries of the national economy [2]. Cultural products contain aesthetics and symbolic symbols, which can cater to the needs of consumers to satisfy their self-awareness and spiritual pursuits [3–5]. The ability to innovate is endowed with cultural products that can reflect the crystallization of people's wisdom and demonstrate the level of national science and technology and cultural development. As a subdivision of cultural products, the animation industry is a new type of industry, with the characteristics of general cultural creativity, and is a sunrise industry vigorously

developed by countries all over the world. There are many factors that affect the development of the animation industry [6]. Among them, cultural differences, cost expansion, and local protectionism are common factors that hinder the development of the animation industry in all countries in the world [7–9]. The improvement of the production efficiency of animation products can save the expenditure costs of animation companies and can play a positive role in promoting the development of the animation industry and even the cultural industry.

1.2. The Production Mechanism and Production Characteristics of Animation Products. The production process of animation products is the guarantee of the value of animation products. After the animation product design is completed, it is the animation production process. The production process of animation products is a step that transforms the creativity in the value chain from concept to reality. In this step, different technical environments have a greater impact on the production efficiency of animation

works, mainly because the technical participation in the production process can save a lot of production. These production costs include personnel input and time consumption. In the animation product value chain, the production process of animation products affects the quality of animation products [10]. The animation production process is the process of transforming conceptual creativity into animation works. The production process of animation products must be strictly based on creativity and design concepts. The quality of animation products will be displayed through the details of the production process [11].

The production characteristics of animation products are determined by the production process. The production process of animation products includes plot outline arrangement, drawing of human design, script creation, storyboard drawing, line draft drawing, special effects, and so on. These production processes have resulted in the production of animation products with the following three characteristics: (1) the production process is highly dependent on production technology and requires more material resources to support; (2) the process-oriented paradigm of production is relatively strong, with a certain degree of regularity and systemicity; and (3) the entire production process requires a lot of human participation, and human investment is the main input item for product manufacturing. It can be seen from the production characteristics of animation products that different heterogeneous technology integration environments will have a great impact on the production of animation products, which will result in different production efficiency of animation products.

1.3. Comprehensive Efficiency Evaluation Research. Comprehensive evaluation methods can be divided into subjective weighting method and objective weighting method [12]. Among them, subjective weighting method refers to analytic hierarchy process and entropy weighting method; objective weighting method includes principal component analysis and factor analysis. In addition, in recent years, some scholars have studied several new evaluation methods, including gray correlation analysis and fuzzy neural network evaluation [13, 14]. Among them, the field of mathematics, which is commonly used in grey relational analysis, is an analysis method to analyze the level of correlation and influence between various indicators in a specific environment [15]. The grey relational analysis method is to quantitatively analyze the data of various indicators and use the order, size, and strength of each influencing factor to carry out dynamic quantitative analysis of the indicators, which has objectivity and reference value [16].

The efficiency measurement methods can be divided into four categories. The first type is the ratio method, that is, output/input. This type of efficiency measurement considers fewer factors and the process is relatively simple; the second type is the parameter method, which is mainly random as represented by the stochastic frontier

analysis (SFA); some scholars have used the stochastic frontier analysis (SFA) model to analyze the level of technical efficiency; the third category is the nonparametric method, and the nonparametric law is based on the data envelopment analysis method (as represented by data envelopment analysis, DEA); the DEA method has the advantages of freely handling the complex problems of multiple input and multiple output indicators without knowing the specific form of the production function [17–19]. Some scholars use DEA or an improved DEA model to measure efficiency because of the production of animation products [20]. The process is a complex activity with multiple inputs and multiple outputs, and it is difficult to determine the relationship of the production function, so it is more appropriate to use the DEA method to measure the efficiency [21, 22]; the fourth category, the combined measurement algorithm, combines the rolling window evaluation method and the Shannon entropy method to measure market information efficiency, using the DEA-Tobit two-step method; this type of method can be used to measure the efficiency of talent development. As a typical efficiency measurement method, DEA can be used not only for efficiency evaluation among clusters, industries, and industries but also for efficiency measurement and comparative analysis within enterprises, universities, and banks. Some scholars used the three-stage DEA to measure the internal management efficiency of various commercial banks [23].

2. Research Model Construction

2.1. DEA Method and Two-Stage DEA Model. DEA, also known as data envelopment analysis (DEA), was first used to calculate the efficiency of enterprises. It was to determine the efficiency of production by analyzing the data of production input and output. In 1953, Malmquist proposed the Malmquist index to analyze and study changes in consumption; in 1957, Fareel developed the Malmquist index and established the DEA-Malmquist index to examine changes in production efficiency. DEA-Malmquist index is based on DEA and combines the advantages of DEA. Through the DEA-Malmquist index, the efficiency of panel data can be analyzed [24]. The calculated efficiency can be further decomposed into technical level and technical efficiency, and technical efficiency can be decomposed into pure technical efficiency and scale efficiency. The expression of the DEA-Malmquist index model is as follows.

Taking time as the base period, the DEA-Malmquist index from the perspective of output is expressed as

$$M_i^t = \left[\frac{d_i^t(x^{t+1}, y^{t+1})}{d_i^t(x^t, y^t)} \right]. \quad (1)$$

Taking time $t + 1$ as the base period, the DEA-Malmquist index from the perspective of output is expressed as

$$M_i^{t+1} = \left[\frac{d_0^{t+1}(x^{t+1}, y^{t+1})}{d_0^{t+1}(x^t, y^t)} \right]. \quad (2)$$

The above two formulas can be used to calculate the change value of the TFPCH from the period t to the period $t + 1$ of the geometric mean measurement time:

$$M_i^{t+1} = \left[\frac{d_i^t(x^{t+1}, y^{t+1})}{d_i^t(x^t, y^t)} \times \frac{d_i^{t+1}(x^{t+1}, y^{t+1})}{d_i^{t+1}(x^t, y^t)} \right]^{(1/2)}. \quad (3)$$

Under the premise of constant return to scale, TFPCH can be decomposed into the product of technical efficiency index (EFFCH) and technological progress index (TECHCH):

$$M_i = \frac{d_i^t(x^{t+1}, y^{t+1})}{d_i^t(x^t, y^t)} \times \left[\frac{d_i^t(x^{t+1}, y^{t+1})}{d_i^{t+1}(x^t, y^t)} \times \frac{d_i^t(x^t, y^t)}{d_i^{t+1}(x^t, y^t)} \right]^{(1/2)}. \quad (4)$$

Among them:

$$\text{EFFCH} = \left[\frac{d_i^{t+1}(x^{t+1}, y^{t+1})}{d_i^t(x^t, y^t)} \right],$$

$$\text{TECHCH} = \left[\frac{d_i^t(x^{t+1}, y^{t+1})}{d_i^{t+1}(x^t, y^t)} \times \frac{d_i^{t+1}(x^{t+1}, y^{t+1})}{d_i^{t+1}(x^t, y^t)} \right]^{(1/2)}, \quad (5)$$

$$\text{TFPCH} = \text{EFFCH} \times \text{TECHCH}.$$

Traditional data envelopment analysis methods mainly include five models: C^2R , BC^2 , C^2GS^2 , C^2W , C^2WH .

Many scholars at home and abroad generally believe that the production efficiency of enterprises should be studied in two stages. The first stage is the development stage of technology [25]. Among them, the technology development stage is mainly resource input, including R&D funds, R&D personnel, and equipment input; the investment at this stage can promote the output of technological innovation results of the enterprise, such as patents, copyrights, and new processes. The second stage is the technology application stage, and it is also the stage where the results of the first stage are transformed into market effects. The principle of the two-stage DEA model is shown in Figure 1.

It can be seen from Figure 1 that, unlike the traditional DEA model, it is assumed in the model that there is no output outflow in the first stage, but the whole input is input into the second stage together with additional input, and the final result is output as $Y_r, r = 1, \dots, s$.

The specific model is constructed as follows. Suppose there are n decision-making units, each decision-making unit has m types of inputs, s types of outputs, and k types of intermediate outputs, and X_i is the input of the first stage of the i decision-making unit (DMU), $X_i = (x_{i1}, x_{i2}, \dots, x_{im})^T$; Z_g is the output of the first stage, and at the same time as the input of the second stage, $Z_g = (z_{g1}, z_{g2}, \dots, z_{gh})^T$; Y_r is the system output of the second stage, $Y_r = (y_{r1}, y_{r2}, \dots, y_{rs})^T$. $V = (v_1, v_2, \dots, v_m)$, $W = (w_1, w_2, \dots, w_k)$,

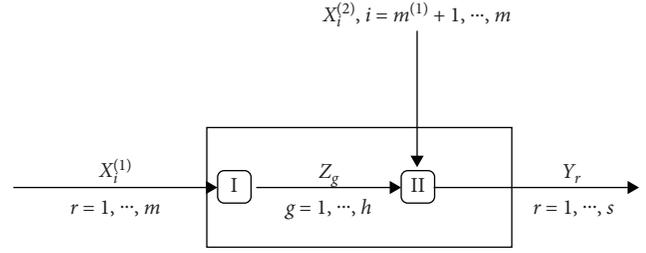


FIGURE 1: Two-stage network DEA model.

and $U = (u_1, u_2, \dots, u_s)$, respectively, represent the weights of input and intermediate output changes, and the two-stage chain DEA model is $E_0 - \max U^Y Y_0$.

$$\begin{cases} V^T x_0 = 1, \\ U^T Y_i - V^T X_i \leq 0, \\ \text{s.t. } W^T Z_i - V^T X_i \leq 0, \\ U^T Y_i - W^T Z_i \leq 0, \\ U \geq \varepsilon e_s, \\ V \geq \varepsilon e_m, \\ W \geq \varepsilon e_k, \end{cases} \quad (6)$$

where ε is the non-Archimedes infinitesimal, $e^T = (1, 1, \dots, 1)$. If U^* , V^* , W^* are the optimal solutions of the model, the efficiency of the overall DMU and the sub-processes is $E_0 = (U^{*T} Y_0 / V^{*T} X_0)$, $E_1 = (U^{*T} Z_0 / V^{*T} X_0)$, $E_2 = (U^{*T} Y_0 / W^{*T} Z_0)$, respectively, where E_0 is the overall efficiency and E_1 and E_2 are the partial efficiencies of the two sub-stages.

2.2. Building a Two-Stage DEA Network System Model That Shares Input Resources. The two-stage DEA network system model that shares input resources also incorporates the “process between input and output” into the efficiency evaluation, so that the results can explain the overall situation more completely and prevent deviations. The specific model is shown in Figure 2.

Suppose there are n decision-making units, DMU $_j$ ($j = 1, 2, \dots, n$); the input of the first stage is X_{ij} ($i = 1, 2, \dots, m$), and the output of the first stage is Z_{pj} ($p = 1, 2, \dots, p$); in the second stage, the reinput is H_{pj} ($h = 1, 2, \dots, g$), and the output is Y_{rj} ($r = 1, 2, \dots, s$). Furthermore, the shared input considers that the initial input has an impact on the output of the two stages. Assuming that the initial input X_{ij} has an effect ratio of α_i ($0 \leq \alpha_i \leq 1$) to the first stage, the input of the first stage is $\alpha_i X_{ij}$, and the initial input of the second stage is $(1 - \alpha_i) X_{ij}$.

Use decision variables v_i^1 and v_i^2 to represent the weight of the initial input in the two stages, respectively; w_p^1 and w_p^2 represent the weight of the intermediate output in the two stages, respectively [26]; f_h is the weight of the reinvestment; u_r is the weight of the output in the second stage. Then, the overall efficiency E_k of the decision-making unit and the

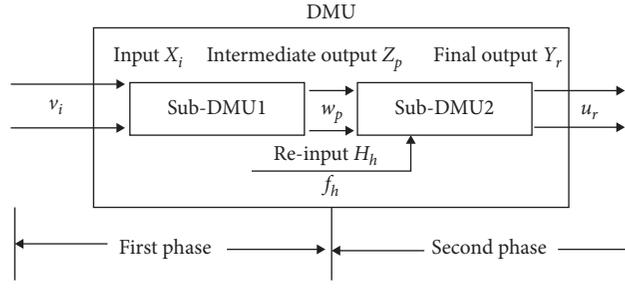


FIGURE 2: Two-stage DEA network system model that shares input resources.

efficiencies E_k^1 and E_k^2 of the sub-processes are shown in the following three formulas:

$$\begin{aligned}
 E_k^1 &= \frac{\sum_{p=1}^q w_p^1 \times Z_{pj}}{\sum_{i=1}^m v_i^1 \times \alpha_i \times X_{ij}}, \\
 E_k^2 &= \frac{\sum_{r=1}^s u_r \times Y_{rj}}{\sum_{i=1}^m v_i^2 \times (1 - \alpha_i) \times X_{ij} + \sum_{p=1}^q w_p^2 \times Z_{pj} + \sum_{h=1}^g f_h \times H_{hj}}, \\
 E_k &= \frac{\sum_{p=1}^q w_p^1 \times Z_{pj} + \sum_{r=1}^s u_r \times Y_{rj}}{\sum_{i=1}^m v_i^1 \times \alpha_i \times X_{ij} + \sum_{i=1}^m v_i^2 \times (1 - \alpha_i) \times X_{ij} + \sum_{p=1}^q w_p^2 \times Z_{pj} + \sum_{h=1}^g f_h \times H_{hj}}.
 \end{aligned} \tag{7}$$

Using mathematical programming ideas, a fractional mathematical programming of a two-stage DEA model with shared input correlation is constructed to obtain the maximum efficiency. At the same time, in order to prevent the optimal solution of the requested variable from being zero,

set its lower limit to Archimedes infinitesimal (ε), thereby converting the fractional mathematical programming into an equivalent linear programming, as shown in the following formula:

$$\begin{aligned}
 E_k &= \max \left(\sum_{p=1}^q w_p^1 \times Z_{pk} + \sum_{r=1}^s U_r \times Y_{rk} \right) \\
 \text{s.t.} & \begin{cases} \sum_{i=1}^m \pi_i^1 \times X_{ij} - \sum_{p=1}^q W_p^1 Z_{pj} \geq 0, \\ \sum_{i=1}^m V_i^2 \times X_{ij} - \sum_{i=1}^m \pi_i^2 \times X_{ij} + \sum_{p=1}^q W_p^2 \times Z_{pj} + \sum_{h=1}^g F_h \times H_{hj} - \sum_{r=1}^s U_r \times Y_{rj} \geq 0, \\ \sum_{i=1}^m \pi_i^1 \times X_{ik} + \sum_{i=1}^m V_i^2 \times X_{ik} - \sum_{i=1}^m \pi_i^2 \times X_{ik} + \sum_{p=1}^q W_p^2 \times Z_{pk} + \sum_{h=1}^g F_h \times H_{hk} = 1, \\ V_i^2 \geq \pi_i^2 \geq \varepsilon, \pi_i^1, W_p^1, W_p^2, F_h, U_r \geq \varepsilon, i = 1, 2, \dots, m; j = 1, 2, \dots, n, \end{cases}
 \end{aligned} \tag{8}$$

where $V_i^1 = t \times v_i^1, V_i^2 = t \times v_i^2, W_p^1 = t \times w_p^1, W_p^2 = t \times w_p^2, F_h = t \times f_h, U_r = t \times u_r$.

$$t = \frac{1}{\sum_i^m v_i^1 \times \alpha_i \times X_{ik} + \sum_{i=1}^m v_i^2 \times (1 - \alpha_i) \times X_{ik} + \sum_{p=1}^q u_r \times Z_{pk} + \sum_{h=1}^g f_h \times H_{hk}} \tag{9}$$

From the above calculation, the following can be obtained: animation enterprise production efficiency E_k and $\pi_i^1, \pi_i^2, V_i^1, V_i^2, W_i^1, W_i^2, F_h, U_r, \alpha_i$.

Finally, the first-stage efficiency E_k^1 and the second-stage efficiency E_k^2 are calculated by the following two formulas:

$$E_k^1 = \frac{\sum_{p=1}^q w_p^1 \times Z_{pk}}{\sum_i^m v_i^1 \times \alpha_i \times X_{ik}} = \frac{\sum_{p=1}^q W_p^1 \times Z_{pk}}{\sum_i^m V_i^1 \times X_{ik}},$$

$$E_k^2 = \frac{\sum_{r=1}^s U_r \times Y_{rk}}{\sum_{i=1}^m V_i^2 \times (1 - \alpha_i) \times X_{ik} + \sum_{p=1}^q W_p^2 \times Z_{pk} + \sum_{h=1}^g F_h \times H_{hk}} \tag{10}$$

As far as the efficiency of animation companies is concerned, there is no significant difference between the initial input and intermediate output of the animation production process. Referring to the research of some scholars, we set the first stage of resource input to the second stage with the same amount, so $V_i^1 = V_i^2 (i = 1, 2, \dots, m), W_p^1 = W_p^2 (p = 1, 2, \dots, q)$.

3. Index System Construction and Data Sources

3.1. Index System Construction. The basis for the two-stage division of the two-stage DEA network system model for the construction of shared input resources is to evaluate the production effects of animation products from two dimensions. The first dimension refers to the production efficiency of animation products, corresponding to the first stage in the model; the second dimension refers to the quality of the animation products produced, and the efficiency is measured by the market performance after the release of the animation products, corresponding to the model in the second stage. Since the output of the first stage is animation products, it will be used as the input of the second stage. In summary, this research is a study on the value transfer of animation products from design and production to market feedback and production quality. The efficiency measured in the first phase is the production efficiency of animation products (based on the number of animation products produced), and the second phase is used to measure the quality of the animation products produced in the first phase; the final value output of the animation company efficiency is the comprehensive feedback of the production efficiency of animation products and the quality and efficiency of animation products. The indicator system of this study will be constructed according to the specific meaning of the established two-stage DEA network system

model of shared input resources. The production efficiency indicator system of animation enterprises is shown in Table 1.

3.2. Sample Selection and Data Sources. All data selected in this study come from a typical enterprise in China's animation industry. Through investigation, the researcher obtained the data of the company from June 2016 to June 2019, a total of 36 months in three years, and a total of 36 sets of observation variables. Among them, the data corresponding to the output indicators of the second stage refer to the output of the products produced by the surveyed company in the next six months in the statistical month, namely, the cumulative collection of the next six months, the cumulative number of clicks of the next six months, and the total amount of cumulative payments in the next six months.

4. Model Result Analysis

Based on the above-established model and selected indicator system, the two-stage DEA network system model of shared input resources is used to comprehensively calculate the production efficiency of a Chinese animation production company for a total of 36 months in 3 years (total decision-making units: 36). The calculation results are shown in Table 2. In Table 2, DMU represents the decision-making unit, E_k represents the overall efficiency, E_k^1 represents the efficiency of the first stage, and E_k^2 represents the efficiency of the second stage.

According to Table 2, it can be analyzed that the maximum value of overall efficiency E_k , first-stage efficiency E_k^1 , and second-stage efficiency E_k^2 are all 1. Among them, the minimum value of the overall efficiency E_k is 0.34087 and the average value is 0.72843; the minimum value of the first-stage efficiency E_k^1 is 0.42766, and the average value is

TABLE 1: Product production efficiency index system of animation enterprises.

First-stage investment	First-stage output	Second-stage investment	Second-stage output
Total staff salary expenditure	Number of works produced	Total staff salary expenditure	Total the amount of collection
Office rent	Number of copyright applications	Office rent	Accumulated clicks
Equipment and software purchase or use expenses	—	Equipment and software purchase or use expenses	—
Management funding	—	Management funding	Total accumulated payment
—	—	Advertising costs	—

TABLE 2: Two-stage DEA network system model calculation results of shared input resources.

DMU	E_k	E_k^1	E_k^2	DMU	E_k	E_k^1	E_k^2
1	0.43177	0.71575	0.30904	19	0.78261	0.94257	0.73767
2	0.42766	0.79706	0.34087	20	0.80670	0.99263	0.80076
3	0.47895	0.76324	0.36555	21	0.84476	1.00000	0.84476
4	0.51308	0.75214	0.38591	22	1.00000	1.00000	1.00000
5	0.51365	0.80483	0.41340	23	0.89492	0.94359	0.84443
6	0.56234	0.84083	0.47284	24	0.94697	0.91021	0.86194
7	0.58746	0.92773	0.54500	25	1.00000	0.92006	0.92006
8	0.56194	0.93293	0.52425	26	0.95848	0.93501	0.89619
9	0.72744	0.88199	0.64159	27	0.99653	0.97494	0.97156
10	0.69748	0.96982	0.67643	28	0.95819	0.96293	0.92267
11	0.68514	1.00000	0.68514	29	0.93465	1.00000	0.93465
12	0.59351	0.89792	0.53292	30	0.96296	1.00000	0.96296
13	0.65217	0.82416	0.53750	31	0.94327	1.00000	0.94327
14	0.74739	0.78955	0.59010	32	0.96485	0.98819	0.95346
15	0.86429	0.77253	0.66769	33	0.95621	1.00000	0.95621
16	0.83068	0.80247	0.66659	34	0.98273	0.98542	0.96840
17	0.73913	0.90671	0.67018	35	1.00000	0.98718	0.98718
18	0.73913	0.93687	0.69247	36	1.00000	1.00000	1.00000

0.78575; the minimum value of the second-stage efficiency E_k^2 is 0.79706, and the average value is 0.91275. Therefore, this research can conclude that the production efficiency of animation products of the company has been significantly improved within three years; among them, the overall efficiency E_k has increased the most significantly, followed by the first-stage efficiency E_k^1 , and the second-stage efficiency E_k^2 has increased relatively slowly.

5. Conclusions

In the context of the continuous deepening of the market economy, the importance of efficiency improvement by animation companies is beyond doubt. Therefore, an effective evaluation and analysis of the efficiency of animation companies can enable animation companies to more objectively recognize their own development trends and operating conditions. This study uses a two-stage DEA network system model of shared input resources to evaluate and analyze the production efficiency of animation companies, the market performance of animation products produced, and the overall efficiency of animation companies.

Research shows that the production phase rate, market effect, and overall efficiency of animation products produced

by animation companies in the growth period are showing a trend of rising volatility. In order to improve efficiency, animation companies should optimize their resource allocation capabilities, formulate reasonable and effective development plans and operating models, drive industrial development with technological innovation, and continuously enhance their brand value.

Data Availability

The data presented in this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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