Utilizing Fuzzy Comprehensive Evaluation Mechanism for Theater Performance Scheduling Management in China

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The prevailing theater industry requires new state-of-the-art mechanisms for better evaluation so as to meet the expectations of the audience and to capture the attention of more and more public, thereby making the industry profitable. In modern times, when technology is employed in approximately all walks of life, it is necessary to come up with an automated system that can evaluate the performance of theaters effectively, can provide with more efficient scheduling mechanisms for better management of human resource and other assets, and can improve the traditional booking and reservation mechanisms. This paper proposes a fuzzy logic-based comprehensive evaluation system to closely examine the theater performance in order to construct an intelligent model for rational arrangement of the theater performances as per the demand of the audience. From the perspective of e-commerce, an advanced ticketing system is proposed for better user experience where online reservation of theater seats is performed by using the online facility. This also provides real-time scenario of reservation/availability of seats for a particular program so that the user can make reservations as per his/her preferred schedule. The proposed model is rigorously tested and statistically studied to support the theoretical claims of the research. From the results of the chart analysis, it could be noticed that the evaluation model proposed in this paper is very effective.

1. Introduction

The traditional theater management and scheduling systems are unfortunately operating sluggishly with insufficient functional development where resources are wasted at huge level. As a performing arts institution, the management and performance schedule is the core of the theater. This situation calls for a better modern solution to effectively manage the performances and schedule of the theater activities as per demand. After years of practice and exploration, the National Centre for the Performing Arts has proposed a performance organization management system with “performance period management” as the core, professional division of labor, interlocking, and clear lines as the principles. The success of this system is the key to the scientific, efficient, and sustainable operation of the National Grand Theater. Strengthening the research on the management of theater performances is conducive to transforming the status quo of extensive theater expansion, improving the overall level of the theater industry in the country, and realizing the original intention of theater construction. With such a professional and institutionalized operation and management model of theater performances, the National Grand Theater has not only obtained sufficient economic benefits but also met the diverse spiritual and cultural needs of the public [1].

Over the past ten years, the National Centre for the Performing Arts has adhered to the people-centered creative guidance by continuously establishing and improving the production system of repertoires and creating a series of operas, dramas, Peking operas, and dance dramas [2]. However, even a century-old theater with such a rich history can only produce about three or four new dramas every year. Strengthening performance scheduling management is a manifestation of cultural self-confidence which not only collects the world’s best art products but also brings Chinese culture to the world with its own distinctive qualities and integrates as well as influences the world [3].
Based on the fuzzy comprehensive evaluation method, this paper evaluates and analyzes theater performance scheduling management by constructing an intelligent evaluation model and conducts system verification with experimental research to improve theater performance scheduling management effects. The contributions made through the current research include the following:

1. Proposal of a better scheduling system for theater considering the performance and demands of the audience.
2. Utilization of fuzzy logic to make better guess while performing judgments in evaluating theater performances.
3. Development of a complete e-commerce system which supports multiple functions including automated seat allocation system for online reservation of seats in a theater and ensuring the actual seat availability view in real time.
4. Utilization of the Bayesian diagnostic network model for better management during theater performances and to evaluate it via triangular distribution.
5. The empirical evaluation of the system and presentation of results in both tabular and graphical forms for better understanding of the researchers.

2. Related Work

Fuzzy mathematics is the inevitable result of the development of objective reality, and its development process is the same as the emergence of any emerging discipline. Sun et al. [4] utilized the fuzzy set theory, which is a method of describing the intermediate transition of the difference in the degree of subordination and using the correct mathematical language for describing the ambiguity. The strong penetration and vitality of fuzzy mathematics is slowly emerging, and it is initially applied to many aspects such as fuzzy control, fuzzy recognition, fuzzy cluster analysis, fuzzy decision making, and information retrieval [5].

In just a few decades, predictive/constructive mathematics and classical mathematics have developed together, forming many new branches that penetrate each other [6]. While traditional mathematics deal with absolute concepts and sets, there are many problems where the mathematical logic is not very precise. Importantly, the imprecise way of looking at things and manipulating them is much more powerful than precise way of looking at them and manipulating them. Interestingly, classical distance measurement theory is a further abstraction and extension of Lebesgue measurement and Lebesgue integration which mainly studies measurement and integration in general sets [7]. In simple words, measurement is a measurement scale in the geometric region, and the probability measurement that satisfies the possibility of addition is a special case of classical measurement [8]. If measurement errors are unavoidable or contain subjective judgments or if there is possibility of measurement problems related to non-iterative experiments, then such problems cannot be fully described. However, the degree of ambiguity can be used as a broad framework to explain the importance of things to rationally integrate this information [9]. Studying the fuzzy measurement of special structure can describe the uncertainty of the special form of things in the framework of consistent structure, which is conducive to the application of practical problems [10].

Based on the concept of generalization, the generalization possibility of two general non-additive measurements could be studied, and the error estimation between generalization possibility and general addition could be predicted [11]. Pham et al. [12] employed the concept of new order and order convergence in the subset of m-dimensional space by specifically studying the pseudo-self-continuity and uniform pseudo-self-continuity of fuzzy measurement in the sense of the new order. On the other hand, Enshaei et al. [13] used the Hausdorff distance to define the set-valued ambiguity in a set class composed of a completely non-empty bounded closed subset of the normed space X.

Chou and Bui [14] recently utilized artificial intelligence and fuzzy mathematics for the evaluation and design of heating and cooling systems in new building designs. These studies encourage us to study the evaluation effect of fuzzy measure and fuzzy integral in theater performance scheduling management systems.

3. Mathematical Model of Fuzzy Comprehensive Evaluation Decision

The problem of fuzzy comprehensive judgment decision making is the continuous improvement of the complexity of things. Therefore, many factors must be considered comprehensively when making a decision that will integrate into a final decision which requires a complete model formation for the process [15].

3.1. Multiattribute Fuzzy Comprehensive Evaluation Model. We set \( U = \{u_1, u_2, \ldots, u_n\} \) as \( n \) kinds of factors and \( V = \{v_1, v_2, \ldots, v_m\} \) as \( m \) kinds of judgments. The number and names of their elements can be subjectively stipulated as per the requirements of the actual problems. Due to different positions, various factors have different effects. Since the weights are different from each other, the judgments made are also diverse, i.e., people do not absolutely affirm or deny \( m \) kinds of judgments, so the comprehensive judgment should be a fuzzy subset in \( V \):

\[
B = (b_1, b_2, \ldots, b_m) \in F(V),
\]

where \( b_j \) \((j = 1, 2, \ldots, m)\) reflects the status of the \( j \)-th evaluation \( v_j \) in the comprehensive evaluation, i.e., the degree of membership of \( v_j \) to the fuzzy set \( B \) as depicted in the following equation:

\[
\mu_B(v_j) = b_j.
\]

In essence, the comprehensive evaluation \( B \) depends on the weight of each factor, and it should be a fuzzy subset of \( u \) [16] as given in the following equation:
\( A = (a_1, a_2, \ldots, a_n) \in F(U), \)  
\( \sum_{i=1}^{n} a_i = 1, \)

where \( a_i \) represents the weight of the \( i^{th} \) factor, so once the weight \( A \) is given, a comprehensive judgment \( B \) can be obtained accordingly, thereby establishing a fuzzy transformation \( T \) from \( U \) to \( V \). If a separate judgment \( f(u_i) \) is to be made for each factor \( u_i \), then it can be regarded as a fuzzy projection \( f \) from \( u \) to \( V \) as represented in the following equation:

\[ f: U \rightarrow F(V), u_i \mapsto f(u_i) \in F(V). \]

As anticipated in equation (5), \( f \) presents a fuzzy linear transformation “\( m \)” from “\( T \)” to “\( V \)” which portrays “\( T \)” as a mathematical model that comprehensively judges “\( B \)” by weight \( A \).

From the aforementioned analysis, it can be seen that the mathematical model of fuzzy comprehensive decision-making consists of three element groups containing 4 steps:

1. Factor set \( U = \{u_1, u_2, \ldots, u_n\} \).
2. Evaluation set \( V = \{v_1, v_2, \ldots, v_m\} \).
3. Single-factor evaluation: the fuzzy mapping \( f: U \rightarrow F(V), u_i \mapsto f(u_i) = (r_{i1}, r_{i2}, \ldots, r_{im}) \in F(V) \) can induce the fuzzy relationship \( R \in F(U \times V) \) as

\[ R (u_i, v_j) = f(u_i)(v_j) = r_{ij}. \]

So, overall, \( R \) can be expressed by the fuzzy matrix \( R \in \mu_{RM} \) as given in the following equation:

\[ R = \begin{pmatrix}
  r_{11} & r_{12} & \cdots & r_{1m} \\
  r_{21} & r_{22} & \cdots & r_{2m} \\
  \vdots & \vdots & & \vdots \\
  r_{n1} & r_{n2} & \cdots & r_{nm}
\end{pmatrix}, \]

where “\( R \)” represents the single-factor judgment matrix.

4. Comprehensive evaluation: when the weight \( A = (a_1, a_2, \ldots, a_n) \) exceeds the calculation result of the model \( M (\land, \lor) \) by evaluating the composite calculation result of max–min, the comprehensive evaluation result can be obtained.

The overall conversion process is shown in Figure 1.

\[ B = A \ast R. \]

So, for an input weight \( A \in F(U) \), the corresponding comprehensive evaluation output is given by the following equation:

\[ B = A \ast R \in F(V). \]

3.2 Multiattribute Fuzzy Comprehensive Decision-Making Model. Once multiattribute fuzzy comprehensive evaluation model is formed, it is important to derive the corresponding decision-making model. Consider \( C = \{c_1, c_2, \ldots, c_m\} \) as the “\( m \)” solutions of a certain problem and \( U = \{u_1, u_2, \ldots, u_n\} \) as the attribute set; it is necessary to evaluate and compare each scheme through the attribute set \( U \) in order to select the best scheme. In short, each plan needs to be comprehensively evaluated through the above model, and then the results of different plans are compared to make a decision.

The steps of multiattribute decision-making are depicted in Figure 2.

It can be seen from the above mathematical model of fuzzy comprehensive determination that the weight represents the status or role of each element in the decision. Therefore, the determination of the weight occupies an important position in the fuzzy comprehensive decision, and its evaluation directly affects the decision result. Hence, it is necessary to provide a reasonable request model as an auxiliary means of decision making.

The basic idea of the fuzzy cluster analysis method lies in the fact that if the evaluation index is a fuzzy index, then the fuzzy cluster analysis method can be used to divide the index into different categories according to different thresholds, and the resultant indexes could be sorted as per the classification criteria.

The domain of the index evaluation system could be represented as \( U = \{u_1, u_2, \ldots, u_n\} \) where each evaluation index \( u_i \) is described by its degree of membership to “\( n \)” samples:

\[ u_i = \{x_{i1} = \mu_1 (u_i), x_{i2} = \mu_2 (u_i), \ldots, x_{in} = \mu_n (u_i)\}. \]

Hence, the initial matrix is obtained via the following equation:
The specific steps for the purpose are as follows:

The first step is to normalize the initial data matrix as given in equations (12) and (13):

\[ Y = \{y_{ij}\}_{m \times n}, \quad y_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}}. \]  

The second step is to establish a fuzzy similarity matrix. The possible combinations \((u_i, u_k)\) of all indicators in the universe "u" are calculated, and the fuzzy similarity coefficients of all combinations are computed using the number product formula:

\[ R = \{r_{(u_i, u_k)}\} = \{r_{ik}\}_{m \times n} = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{pmatrix}, \]

\[ r_{ij} = \begin{cases} 1, & i = j, \\ \frac{1}{M} \sum_{l=1}^{n} y_{il}, & i \neq j, \end{cases} \]

where

\[ M = \max_{i,j} \left( \sum_{l=1}^{m} x_{il} \cdot x_{jl} \right), \quad (i = 1, 2, \ldots, m; \quad j = 1, 2, \ldots, n). \]

The third step is to find the fuzzy equivalent matrix according to the obtained fuzzy similarity matrix. If the transitivity is not satisfied, the transitive closure of the fuzzy similarity matrix "R" is required. The quadratic method is commonly used to find the transitive closure of \(R\) as given below:

\[ t(R): R \rightarrow R^2 \rightarrow R^4 \rightarrow \ldots \rightarrow R^{2^l} \rightarrow \ldots. \]

When \(R^k \circ R^k = R^k\) appears for the first time, \(R^k\) is the desired transitive closure \(t(R)\) representing the desired fuzzy equivalent matrix.

The fourth step is classification. Through \(t(R)\), clustering is performed according to an appropriate threshold \(\lambda\) from large to small, and the attribute names and numbers of various categories caused by different \(\lambda\) are recorded. For different \(\lambda \in [0, 1]\), different classifications can be obtained to form a dynamic clustering graph. Furthermore, according to the classification situation, the importance ranking of the indicators is also determined. However, in practical problems, in order to obtain a definite classification of the sample, it is necessary to select a threshold \(\lambda\) in advance. In order to solve the threshold problem, the "F-statistic" method is popularly used to obtain a more reasonable \(\lambda\) as explained in the following text:

First step is to find the center vector \(\bar{x}\) of the population sample by using the original data matrix with the following formula [22]:

\[ \bar{x}_k = \frac{1}{n} \sum_{i=1}^{n} x_{ik}. \]  

The classification number of the \(\lambda\) is denoted by "\(r\)" and \(n_j\) number of samples of the \(j^{th}\) class are denoted as \(x_{1j}, x_{2j}, \ldots, x_{nj}\), while the cluster center vector of the \(j^{th}\) class is represented as \(\bar{x}^{(j)} = (x_{1j}^{(j)}, x_{2j}^{(j)}, \ldots, x_{nj}^{(j)})\).

Finally, the F-statistics are computed as given in the following equation:

\[ F = \frac{\sum_{j=1}^{r} n_j \|x^{(j)} - \bar{x}^{(j)}\|^2 / (r - 1)}{\sum_{i=1}^{r} \sum_{j=1}^{n_i} \|x_i^{(j)} - \bar{x}^{(j)}\|^2 / (n - r)}, \]

\[ \|x^{(j)} - \bar{x}\|^2 = \sum_{k=1}^{r} (x_k^{(j)} - \bar{x}_k)^2, \]

where equation (20) represents the distance between \(\bar{x}^{(j)}\) and \(\bar{x}\) while \(\|\bar{x}^{(j)} - \bar{x}\|\) is the distance between the \(i^{th}\) sample \(x_i^{(j)}\) in the \(j^{th}\) category and its center \(\bar{x}^{(j)}\). The F-statistic is an \(F\)-distribution with degrees of freedom \(r - 1\) and \(n - r\). Here, the numerator reflects the distance between different
categories, and the denominator represents the distance between samples in the same category. Therefore, larger $F$ value will result in greater difference between classes.

Since the fuzzy cluster analysis method can handle continuous data but only determines the order of the importance of the indicators and cannot determine the distribution of specific weight values of the indicators, this method must be used in combination with other methods.

4. Theater Performance Schedule Management Evaluation System Based on Fuzzy Comprehensive Evaluation

According to demand analysis, for various factors related to the performance schedule, users can be classified from the perspective of system permissions to facilitate the practical application of various users. The system divides users into four types, i.e., administrators, schedulers, movie viewers, and tourists. From a functional point of view, the system mainly includes scheduler management, audience management, performance plan management, studio management and performance task release, intelligent scheduling, serial management, various comprehensive surveys, performance time management, and human-computer interaction output modules. The flowchart of intelligent performance arrangement for the proposed system is shown in Figure 3.

The establishment of the Bayesian network diagnostic model is utilized by the current study mainly to determine the nodes in the model and the mutual causality between nodes. The establishment of the model is mainly through data collection, searching for literature and expert opinions. It is an important core network method for management during theater performances. The schematic diagram of Bayesian network is shown in Figure 4.

The factors that affect the performance time of each theater are scored, calculated as a percentage, and the scores obtained are substituted into the triangular distribution, and after normalization, the influence matrix of each element is obtained. It is important to note that the triangular distribution is a continuous probability distribution where the probability density function is shaped like a triangle. It provides a very useful insight in real-life functions where the maximum and minimum values are estimated along with the most likely outcome. That is why it suits well to the fuzzy-based prediction systems. The distribution of triangles for current study is shown in Figure 5.

The management platform of the theater performance mainly includes the front-end ticket purchase APP, the electronic back-end service module, the API interface service center, and the basic data synchronization module in the overall structure. The proposed system architecture diagram is shown in Figure 6.

Using the proposed architecture, the user can see the model through the online e-commerce network, as depicted in Figure 7.

When the left (vacant) seat is selected, the system is updated automatically by marking the particular seat so that other users cannot select it again, as shown in Figure 8.
Figure 6: Design diagram of system architecture.

Figure 7: The model of the performance hall when the theater is not open.
where the orange seats have been reserved by the users while the white seats are not yet sold and so are available for other users to choose/buy it.

From the perspective of software engineering, the three-dimensional structure design of the system is an extremely important part of the entire system’s research and development that can play a guiding role from the perception till the final implementation of the system and even determine its success and failure. So, the structure of the software system directly determines the quality of the system. A good system design can efficiently and stably realize various functions, and while meeting the needs of the enterprise, it ensures the good scalability of the system. When new requirements are requested by the customer that contain no major system structural changes, the requirements could be easily incorporated. The structure of such a system designed according to the requirements can ensure the availability and acceptability of the system. The main goal of structural design is to design the basic architecture of the target system in combination with the previous business requirement analysis and existing technical means. The ticket sales and management system of the theater is a system that requires quick response speed and a better user interface experience. At the same time, as per the need of the customers, client/server (C/S) is selected as the basic architecture mode of the system which is a well-known software system architecture that operates by assigning tasks to the right client, thereby reducing the communication overhead caused by terminal and the server. This also results in better utilization of hardware at both server and terminal ends. On the other hand, browser/server (B/S) is an improvement introduced recently, where the programmer’s job is made easy by dividing the terminals job into front-end and back-end technologies. Considering the flexibility and coherence of C/S architecture and provision of better user authentication and authorization support, it is found to be more suitable for the design and development of current system. The structure of the proposed system is intuitively divided into three types: user layer, business layer, and data layer, as shown in Figure 9.

5. Test and Analysis of Evaluation System of Theater Performance Scheduling Management Based on Fuzzy Comprehensive Evaluation

After constructing an evaluation model of theater performance scheduling management based on fuzzy judgment, the model is tested to evaluate its performance. For this purpose, a system response test analysis is conducted which uses multiple sets of data to analyze the trend of changes in the corresponding time with online users. The results obtained are shown in Table 1 and Figure 10, respectively.

As depicted in Figure 10, the response effect of the system is principally consistent with the actual situation, so when the number of users increases, it can meet the actual needs. Conclusively, the study analyzes the evaluation effect of the theater performance scheduling evaluation model, and the results are shown in Table 2 and Figure 11.

From Figure 11, it could be observed that the theater performance scheduling management evaluation model based on fuzzy comprehensive evaluation constructed in this study yields promising results which supports its
6. Conclusion

The evaluation of theater performance scheduling management system is of great significance to improve the efficiency of theater management and scheduling which optimizes and enhances the performance while reducing the operational costs. Based on the fuzzy comprehensive evaluation algorithm, this paper constructs a theater performance scheduling management evaluation model. From the perspective of e-commerce, this paper uses fuzzy comprehensive evaluation algorithm to construct an intelligent model, rationally arrange theater performances according to the actual situation of the theater, and build an e-commerce ticketing system to improve user experience from the acceptability and motivates further in-depth research for implementations at larger level.

### Table 1: The trend of response time when the number of users increases.

| Num | Response time (s) | Num | Response time (s) | Num | Response time (s) |
|-----|-------------------|-----|-------------------|-----|-------------------|
| 1   | 2.260             | 18  | 4.739             | 35  | 7.778             |
| 2   | 2.497             | 19  | 4.746             | 36  | 7.800             |
| 3   | 2.517             | 20  | 4.855             | 37  | 7.853             |
| 4   | 2.827             | 21  | 4.879             | 38  | 8.093             |
| 5   | 2.839             | 22  | 4.955             | 39  | 8.299             |
| 6   | 3.026             | 23  | 4.995             | 40  | 8.417             |
| 7   | 3.033             | 24  | 5.222             | 41  | 8.448             |
| 8   | 3.736             | 25  | 5.430             | 42  | 8.709             |
| 9   | 3.808             | 26  | 5.492             | 43  | 8.942             |
| 10  | 3.874             | 27  | 5.652             | 44  | 9.189             |
| 11  | 3.928             | 28  | 5.731             | 45  | 9.262             |
| 12  | 4.069             | 29  | 5.736             | 46  | 9.263             |
| 13  | 4.183             | 30  | 5.781             | 47  | 9.360             |
| 14  | 4.346             | 31  | 6.372             | 48  | 9.404             |
| 15  | 4.383             | 32  | 6.408             | 49  | 9.471             |
| 16  | 4.634             | 33  | 6.994             | 50  | 9.489             |
| 17  | 4.667             | 34  | 7.321             | 51  | 9.503             |

![Figure 10: Statistical diagram of the trend of response time when the number of users increases.](image1)

![Figure 11: Statistical diagram of the evaluation effect of the theater performance scheduling management evaluation model.](image2)

### Table 2: The evaluation effect of the theater performance scheduling management evaluation model.

| Num  | Evaluate | Num  | Evaluate | Num  | Evaluate |
|------|----------|------|----------|------|----------|
| 1    | 80.861   | 18   | 92.987   | 35   | 91.943   |
| 2    | 90.111   | 19   | 87.102   | 36   | 89.740   |
| 3    | 90.074   | 20   | 79.612   | 37   | 87.665   |
| 4    | 92.085   | 21   | 86.695   | 38   | 80.544   |
| 5    | 90.666   | 22   | 92.302   | 39   | 90.505   |
| 6    | 93.267   | 23   | 89.366   | 40   | 88.681   |
| 7    | 90.909   | 24   | 86.601   | 41   | 84.910   |
| 8    | 80.841   | 25   | 91.297   | 42   | 81.268   |
| 9    | 83.582   | 26   | 80.489   | 43   | 85.948   |
| 10   | 85.412   | 27   | 82.657   | 44   | 81.443   |
| 11   | 80.294   | 28   | 80.391   | 45   | 86.169   |
| 12   | 86.008   | 29   | 82.387   | 46   | 87.152   |
| 13   | 87.962   | 30   | 91.679   | 47   | 91.354   |
| 14   | 80.255   | 31   | 86.597   | 48   | 93.070   |
| 15   | 85.515   | 32   | 91.916   | 49   | 86.947   |
| 16   | 87.056   | 33   | 85.929   | 50   | 80.518   |
| 17   | 91.516   | 34   | 79.959   | 51   | 91.943   |

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perspective of customers. In addition, the constructed model utilizing fuzzy judgments is empirically tested for response time and speed and the performance of the theater performance scheduling management is evaluated as well. The experimental results reveal that the intelligent system constructed in this paper can effectively improve the performance of theater performance scheduling by supporting better management implementation, thereby reducing theater performance costs and improving theater operating economy. The proposed study is however tested on the data received from very limited number of theaters, so for better utilization and evaluation, the National Centre for Performing Arts in China can expand the work by applying it on all/maximum theaters across the country. Moreover, the system could be employed in other cultures/regions and may be proved effective across international boundaries.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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