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ORIGINAL RESEARCH

# Evaluation of Nosocomial Infection Management Efficiency Based on the Data Envelopment Analysis Model

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**Background:** This study used data envelopment analysis (DEA), to assess relative efficiency of infection control in different clinical departments of the hospital for performance evaluation purposes.

**Methods:** All wards and departments from January to December 2022 were selected as decision units, and five input and two output indicators related to infection prevention and control were determined using DEA. Pure technical efficiency was evaluated using the Banker–Charnes–Cooper (BCC) model.

**Results:** In the study, the input-output indexes of the 27 clinical departments varied significantly. The average values of technical efficiency, pure technical efficiency, scale efficiency, and comprehensive benefit were 0.987, 0.995, 0.992, and 0.980, respectively. Among the 27 departments, 52% exhibited constant returns to scale, 44% showed increasing returns to scale, and 4% had decreasing returns to scale. In the context of DEA, 44% of the departments were classified as highly efficient, indicating that their input-output ratios had reached an optimal state. Meanwhile, 56% of the departments were identified as non-DEA efficient, suggesting that there was room for improvement in their input-output efficiency.

**Conclusion:** The improvement of input-output indexes of non-DEA effective clinical departments was defined by the BCC model. Use of DMUs could improve the efficiency of inventory control by optimizing the allocation of inventory control resources and refining inventory control measures.

**Keywords:** data envelopment analysis, performance evaluation, hospital infection, efficiency

## Introduction

An effective sanitation system requires skilled professionals, quality infrastructure, dependable resources, adequate funding, and support from evidence-based policies.[1] Hospital efficiency indicators play an irreplaceable role in evaluating the effectiveness of health policies, comparing the performance of health systems, and monitoring the utilization of resources.[2–4] Data Envelopment Analysis (DEA) and Stochastic Frontier Analysis (SFA) are two classic methods for assessing the efficiency of health services, both of which measure efficiency based on the relationship between inputs and outputs. DEA, which accounts for over 90% of applications in the healthcare sector, excels in handling multiple inputs and outputs, varying weights, and changes in returns to scale.[5–7]

Previous studies have employed DEA techniques to measure the efficiency of COVID-19 pandemic control efforts in various states and union territories of India.[8] The Malmquist fuzzy DEA (Mal-FDEA) model approach has been employed to evaluate the technical efficiency of health products across Indian states. By analyzing samples from these states, it has been used to identify which ones possess the most efficient healthcare systems.[9] DEA has also been widely applied in the public healthcare sector, covering subfields such as medical device manufacturing, pharmaceuticals, and



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medical insurance.[10] A large number of previous studies have applied DEA in the field of healthcare efficiency research, mainly divided into four categories: "pure DEA efficiency analysis" "development or application of new methods" "specific management issues" and "investigation of reform impacts".[11]

DEA has been widely used to assess the performance of clinical departments in hospitals. However, its application in the area of hospital infection control efficiency remains limited, and further research is needed to explore its potential in this domain. A study in Norway assessed hospital efficiency using DEA under a DRG-based payment system where hospital costs were allocated to clinical departments. The output measure was the number of discharges adjusted by DRGs, and fixed-effects regression models were used to analyze departmental efficiency. The results showed that pediatric departments generally had lower efficiency.[12] In a study in Turkey, DEA revealed that cardiology and orthopedics had relatively lower service efficiency. Meanwhile, Grey Relational Analysis (GRA) showed that ophthalmology, otolaryngology (ENT), and pediatric surgery ranked as the top three most efficient clinical departments. The most important input indicators were found to be the number of patients and the number of healthcare staff.[13] There have been many studies on the efficiency of acute care hospitals using DEA, with labor and beds as common input indicators, and outpatient visits, surgeries, admission days, and inpatient days as the most common output indicators.[14] The significance of hospital infection prevention and control in ensuring an effective healthcare system is becoming increasingly evident.[15] Performance-based compensation is effective for enhancing infection prevention and control practices in healthcare institutions.[16] The remuneration of medical staff in China follows the "Pay for Performance Strategy (PPS)",[17] with hospital infection-related indicators being a crucial component of performance evaluation. The current evaluation method does not comprehensively consider staffing, the cost of infection control, and the impact of workload on the effectiveness of infection prevention and control measures in clinical departments, and is subject to subjective bias and lacks comprehensive assessment.[18]

DEA is a linear programming model that uses weighted information for multiple input and output indicators for data analysis.[3] This study assessed the effectiveness of infection prevention and control measures in clinical departments of tertiary Grade A hospital, using clinical departments as DMUs and conducted an efficiency analysis of a range of input and output indicators of hospital-acquired infections to provide decision-making support for hospital infection control managers.

This study utilized DEA to conduct an efficiency analysis of input and output indicators related to hospital infection control, with clinical departments of a tertiary hospital serving as decision-making units (DMUs). The objective was to evaluate the effectiveness of infection prevention and control measures in these departments and provide decision-making support for hospital infection control managers. Given the critical importance of hospital infection control and the insufficiency of existing evaluation methods, DEA, despite its widespread application in performance assessment of clinical departments, has been underutilized in the realm of infection control efficiency. The objective of this study was to construct a DEA evaluation model tailored for infection control, quantify departmental efficiency, and identify efficiency disparities through empirical analysis, thereby offering a scientific basis for optimizing hospital infection management. The paper first introduced the research background and methodology, followed by a detailed explanation of the DEA model construction and indicator selection. It then presented the empirical analysis results and proposed improvement recommendations in line with the practical needs of hospital infection management.

# Subjects and Methods

## Subject of Study

This study was conducted in a tertiary hospital located in a city on the east coast of China in 2022. The clinical departments were used as DMUs. The following units were excluded: he day surgery unit (because it generally only provides minor day surgeries such as tooth extraction and hemorrhoidectomy); department units with missing data on input or output indicators; 14 clinical departments without hospital-acquired infections (including Endocrinology, Ophthalmology, Traditional Chinese Medicine, Pediatrics, Gastroenterology Department 2, Obstetrics, Stomatology, Minimally Invasive Intervention, Respiratory Department 1, Urology, Thoracic Surgery, Health Care, Pain Management, Neurology Zone 1). Separate input indicator data could not be obtained for some department units (such as Obstetrics Department Zone 1 and Obstetrics Department Zone 2), so units within the department were merged. Ultimately, data from 27 clinical departments that met the criteria were included in the DEA in 2022.

## Observations, Indicators, and Sources

This study referred to the *Operational Manual for Performance Appraisal of National Level 3 Public Hospitals* (2022),[19] *Evaluation Criteria for Tertiary Hospitals* (2022),[20] and *Quality Control Indicators for Hospital Infection Management* (2021).[21] A preliminary set of infection control efficiency evaluation indicators was developed after conducting a literature review. Before the study began, hospital infection control experts, clinical department specialists, and academic researchers in the hospital management field were invited to suggest indicator modifications. All participants were fully informed about the study's purpose, their involvement, and the confidentiality of their contributions. Written informed consent was obtained from each participant to ensure their voluntary participation and understanding of the study process. Considering the availability of data, the indicators were ultimately refined to include five input indicators (hand hygiene compliance, consumption of infection control materials per inpatient, cost of infection control supplies per inpatient, training and drill frequency, and number of medical staff per inpatient) and two output indicators (hospital infection incidence rate and detection rate of multidrug-resistant bacterial infections).

### Hand Hygiene Compliance

The ratio of the actual implementation of hand hygiene to the expected implementation of hand hygiene was examined. The data were obtained from hand hygiene compliance surveys in the real-time infection monitoring system of the hospital, collected and recorded by both full-time and part-time infection control personnel.

### Consumption of Infection Control Materials per Inpatient

This indicator was the ratio of the amount of infection control supplies used to the total number of hospitalized patients during the same period, that is, the amount of infection control supplies used/total number of hospitalized patients, with the unit being units per patient. This reflected the average amount of clinical infection control supplies used per patient. The data were obtained from various information systems related to the use of infection control supplies. The infection control supplies included hand sanitizers, hand wash, paper towels, disinfectant wipes, and the total amount of chlorine-containing disinfectants. Because infection control supplies comprised five categories of items, each with different unit properties, the measurement units of each infection control supply were standardized and referred to as units.

### Cost of Infection Control Supplies per Inpatient

This indicator was calculated as the product of the amount of various infection control supplies used and their purchase prices divided by the total number of inpatients during the same period, that is, the cost of infection control supplies/total inpatients, with the unit being yuan per person. This reflects the average cost of the clinical infection control supplies per patient. The data were sourced from the hospital's internal logistics management system.

### Training and Drill Frequency

This indicator was the total number of infection control-related trainings and exercises conducted by each clinical department in 2022.

### Number of Medical Staff per Inpatient

This indicator was the ratio of the number of medical staff to the total number of inpatients during the same period, and indicated the mean number of medical staff per patient, with the unit being medical staff per patient.

### Hospital Infection Incidence Rate (%)

This indicator referred to the proportion of cases of hospital-acquired infections per inpatient.[21] The data were derived from the hospital's real-time infection monitoring system, with infection control specialists and responsible physicians referring to the *Hospital Infection Diagnosis Criteria* issued by the Ministry of Health in 2001 to confirm the number of cases of hospital-acquired infections.[22]

### Detection Rate of Multidrug-Resistant Bacterial Infections (%)

This indicator referred to the ratio of the number of cases of multidrug-resistant bacterial infections to the total number of inpatients during the same period. Following the requirements of the *Hospital Infection Management Quality Control Indicators* (2021 Edition), monitored bacterial strains include carbapenem-resistant Enterobacteriaceae, methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant enterococci, carbapenem-resistant *Acinetobacter baumannii*, and carbapenem-resistant *Pseudomonas aeruginosa*. These data were obtained from the hospital's real-time infection monitoring system.

## Research Methodology

Considering the varying scale of technological innovation and unequal competition, which led to some DMUs not operating at an optimal scale, the measurement of technical efficiency (TE) is influenced by scale efficiency (SE). Therefore, this study adopted the BCC model, assuming variable returns to scale and primarily focusing on measuring pure TE.

DEA is a non-parametric technique used to evaluate the relative efficiency of DMUs by comparing their performance against a constructed efficiency frontier. This method is particularly useful for assessing the efficiency of organizations or units where multiple inputs and outputs are involved. DEA does not require pre-specification of a production function, making it highly adaptable to various contexts. The efficiency score for each DMU is determined by solving a linear programming model that maximizes the ratio of weighted outputs to weighted inputs while ensuring that the efficiency scores of all DMUs do not exceed one.[23]

The DEA method offers several key advantages. It is non-parametric, meaning it does not require assumptions about the functional form of the production process, thereby avoiding potential biases. DEA is well-suited for evaluating complex systems with multiple inputs and outputs, making it highly applicable in real-world scenarios. It provides a relative efficiency score for each DMU, which helps identify inefficient units and areas for improvement. Additionally, the DEA model is flexible and can be adjusted based on the evaluation purpose and conditions, offering strong adaptability.[24,25]

In this study, researchers employed the BCC model, which assumes Variable Returns to Scale (VRS). This model is particularly useful for evaluating pure technical efficiency (PTE) by separating the effects of scale efficiency (SE) from technical efficiency. The BCC model is formulated as follows:

For a given DMU $j_0$, the BCC model is expressed as:

$$
\begin{aligned}
& min\theta \\
s.t. \quad & \textstyle\sum_{j=1}^{n}\lambda_j x_{ij} \leq \theta x_{ij0}, i = 1,2\ldots,m \\
& \textstyle\sum_{j=1}^{n}\lambda_j x_{ij} \leq \theta x_{rj0}, r = 1,2\ldots,s \\
& \textstyle\sum_{j=1}^{n}\lambda_j = 1 \\
& \lambda_j \geq 0, j = 1,2\ldots,n
\end{aligned}
$$

where $x_{ij}$ and $y_{rj}$ represent the input and output values for DMU $j$, respectively. The additional constraint $\sum_{j=1}^{n}\lambda_j = 1$ ensures that the model accounts for variable returns to scale.[24]

### Sample Size

As a nonparametric efficiency assessment method, the number of DMUs should typically not be less than the product of the number of input and output indicators, and should be at least three times the sum of the input and output indicators.[26] Ensuring that an adequate number of DMUs adequately reflects the complexity and diversity of decision-making problems, thereby enhancing the accuracy and reliability of decision outcomes.

### Analysis Tools

The descriptive analysis was performed using Stata MP 17 (StataCorp, College Station, TX, USA), efficiency calculations were carried out using DEAP-XP1 software. Lower values are desired for both the hospital infection incidence rate and the multidrug-resistant bacteria infection detection rate; hence, reverse scoring was used to convert the values to positive indicators.

# Results

## Basic Information

Of the 41 clinical departments, 27 met the eligibility criteria in terms of input-output indicators. There were significant variations in the input-output indicators among these 27 departments. The departments with the highest and lowest hand hygiene compliance rates were Emergency Department Zone 1 (98.9%) and General Surgery Department 1 (94.5%), respectively. The departments with the highest and lowest consumption of infection control materials per inpatient were the Cardiac Intensive Care Unit (11.76) and the Oncology Department 1 (0.22) respectively. The departments with the highest and lowest costs of infection control materials per inpatient were the Cardiac Intensive Care Unit ($133.32) and Oncology Department 1 ($2.59), respectively. The departments with the highest and lowest training and drill frequencies were the Respiratory Department 2 (31) and the Department of General Medicine (22), respectively. The departments with the highest and lowest nurse-to-patient ratios per inpatient were the Cardiac Intensive Care Unit (0.154) and Oncology Department 1 (0.007), respectively. The departments with the highest and lowest rates of hospital-acquired infections were the Cardiac Intensive Care Unit (40%) and Obstetrics Department (0.19%), respectively. The departments with the highest and lowest rates of detection of multidrug-resistant infections were the Cardiac Intensive Care Unit 18.5(%) and Oncology Department 2 (0.03%), respectively. An analysis of the input and output indicators is shown in Table 1.

## Efficiency of Hospital Infection Management in Clinical Departments

The mean TE, pure technical efficiency (PTE), SE, and overall efficiency (OE) for the 27 clinical departments were 0.987, 0.995, 0.992, and 0.980, respectively. Among the 27 clinical departments, 14 (52%) had constant returns to scale (CRS), whereas 12 (44%) had increasing returns to scale, with only Neurosurgery showing a decreasing return to scale.

The basis for assessing DEA effectiveness lies in the comprehensive OE value reaching 1, with slack variables S− and S+ both at 0, defining the DEA as strongly effective, indicating that a specific DMUs has achieved maximum efficiency. If the OE value is 1 and either the slack variable S− or S+ is greater than 0, the DEA is defined as weakly effective, indicating that a DMUs possesses relative efficiency but still has room for improvement. If the OE value is less than 1, it the DEA is defined as non-effective, signifying a poor input-output comparison. Among the 27 clinical departments, 12 (44%) showed strong DEA effectiveness, whereas 14 (56%) showed DEA non-effectiveness (Table 2 and Figure 1). The departments of General Medicine, Emergency Zone 1, Oncology Department 2, Oncology Department 1, Infectious Diseases, Cardiothoracic Surgery, Cardiothoracic Intensive Care Unit, Neurology Department 2, Oncology Department 3, Otorhinolaryngology, Pulmonology Department 2, and Burn Unit all demonstrated TE, PTE, and SE values of 1, maintaining CRS, and strong DEA effectiveness.

**Table 1** Descriptive Analysis of Input-Output Indicators of Nosocomial Infection

| Descriptive Statistics | Input Indicators | | | | | Output Indicators | |
|---|---|---|---|---|---|---|---|
| | Hand Hygiene Compliance (%) | Consumption of Infection Control Materials per Inpatient (unit/person) | Cost of Infection Control Supplies per Inpatient (RMB/person) | Training and Drill Frequency (times) | Medical Staff per Inpatient (personnel/person) | Hospital Infection Incidence Rate (%) | Detection Rate of Multidrug-Resistant Bacterial Infections (%) |
| Mean | 96.680 | 1.455 | 16.206 | 26 | 0.030 | 4.730 | 2.200 |
| Std. Dev | 1.280 | 2.466 | 27.554 | 2 | 0.036 | 9.240 | 4.690 |
| Min | 94.470 | 0.216 | 2.590 | 22 | 0.007 | 0.190 | 0.030 |
| Max | 98.920 | 11.762 | 133.317 | 31 | 0.154 | 40.000 | 18.460 |

**Table 2** DEA Analysis Results of Some Clinical Departments

| Department | Technical Efficiency (TE) | Pure Technical Efficiency (PTE) | Scale Efficiency (SE) | Scale Elasticity | Overall Efficiency (OE=TE*SE) | Effectiveness |
|---|---|---|---|---|---|---|
| Hepatobiliary Surgery Department | 0.973 | 0.997 | 0.976 | Increase | 0.950 | Invalid DEA |
| Gastroenterology Department | 0.985 | 0.996 | 0.989 | Increase | 0.974 | Invalid DEA |
| Spinal Surgery Department | 0.971 | 0.986 | 0.985 | Increase | 0.956 | Invalid DEA |
| General Surgery Department, Subjects and Methods | 0.991 | 0.992 | 0.999 | – | 0.990 | Invalid DEA |
| General Surgery Department, Introduction | 0.972 | 0.997 | 0.975 | Increase | 0.948 | Invalid DEA |
| Orthopedics Department | 0.986 | 0.987 | 1.000 | – | 0.986 | Invalid DEA |
| Neurosurgery Department | 0.997 | 0.999 | 0.998 | Decrease | 0.995 | Invalid DEA |
| Vascular Surgery Department | 0.974 | 0.987 | 0.986 | Increase | 0.960 | Invalid DEA |
| Cardiology Department, Introduction | 0.962 | 0.997 | 0.965 | Increase | 0.928 | Invalid DEA |
| Cardiology Department, Subjects and Methods | 0.966 | 0.980 | 0.986 | Increase | 0.952 | Invalid DEA |
| Intensive Care Unit | 0.994 | 0.996 | 0.997 | Increase | 0.991 | Invalid DEA |
| Gynecology Department | 0.983 | 0.997 | 0.986 | Increase | 0.969 | Invalid DEA |
| Emergency Department, Subjects and Methods | 0.944 | 0.972 | 0.971 | Increase | 0.917 | Invalid DEA |
| Nephrology Department | 0.982 | 0.988 | 0.994 | Increase | 0.976 | Invalid DEA |
| General Surgery Department, Introduction | 0.976 | 0.993 | 0.983 | Increase | 0.959 | Invalid DEA |
| Mean | 0.987 | 0.995 | 0.992 | – | 0.980 | – |

## Analysis of Input-Output Improvement in Hospital Infection Management in Clinical Departments

The higher the redundancy rate of the input, the greater the proportion of input reduction required to achieve the target efficiency, and the higher the rate of insufficient output, the greater the proportion of output increase required to achieve the target efficiency. As shown in Table 3, the non-DEA effective input-output indicator improvement in clinical departments, taking the Hepatobiliary Surgery Department as an example, the amount of infection control supplies used per inpatient exceeded the standard input amount by 163.1%, and the output shortage rate of hospital infection

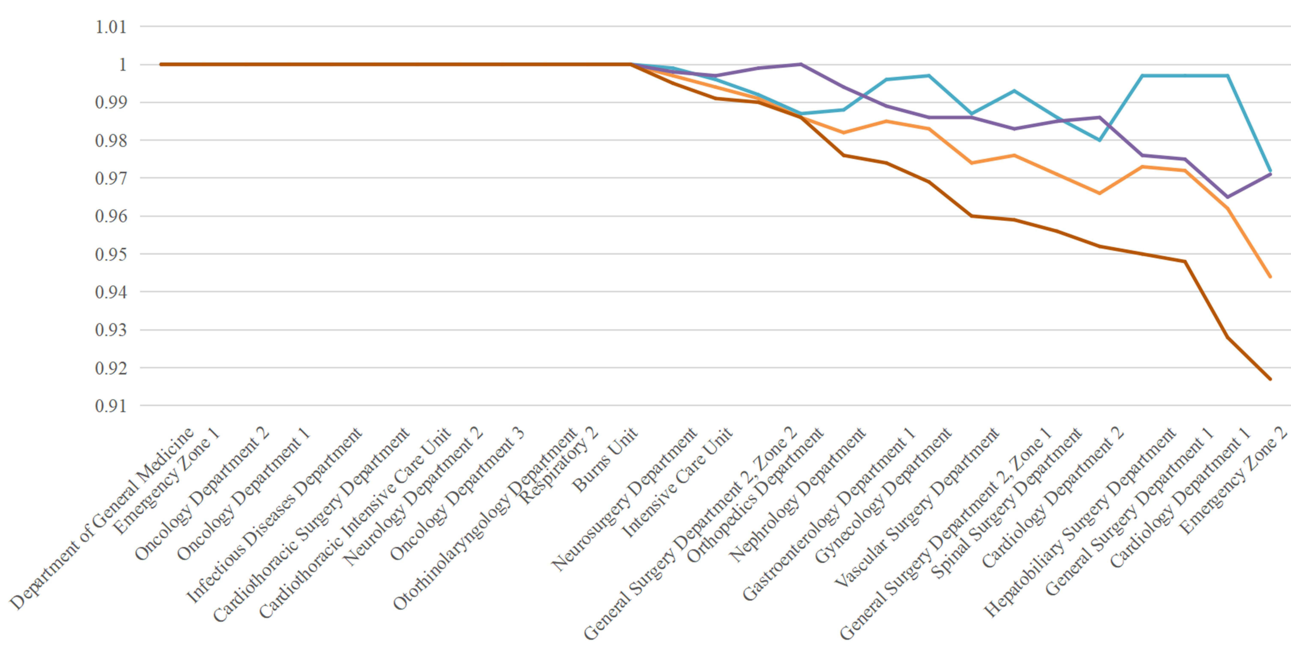


**Figure 1** DEA effectiveness analysis of 27 clinical departments.
**Note**: Different colors in the chart represent various efficiency metrics: orange for technological efficiency (TE), teal for pure technological efficiency (PTE), purple for scale efficiency (SE), and brown for comprehensive efficiency (OE=TE*SE). These metrics illustrate the differences in resource utilization and output efficiency among various clinical departments.

**Table 3** Input-Output Index Improvement of Non-DEA Effective Clinical Departments

| Department | Redundancy rate (%) | | | | | Output Deficiency Rate (%) | |
|---|---|---|---|---|---|---|---|
| | Hand Hygiene Compliance (%) | Consumption of Infection Control Materials per Inpatient (Unit/Person) | Cost of Infection Control Supplies per Inpatient (RMB/ Person) | Training and Drill Frequency (Times) | Medical Staff per Inpatient (Personnel/ Person) | Hospital Infection Incidence Rate (%) | Detection Rate of Multidrug-Resistant Bacterial Infections (%) |
| Hepatobiliary Surgery Department | 0.000 | 263.127 | 0.067 | 0.035 | 0.000 | 2.442 | 0.000 |
| Gastroenterology Department | 37.041 | 230.856 | 0.000 | 0.040 | 0.000 | 0.000 | 0.000 |
| Spinal Surgery Department | 0.000 | 240.217 | 0.000 | 0.062 | 0.000 | 0.000 | 0.000 |
| General Surgery Department, Section Two | 134.480 | 459.000 | 0.000 | 0.030 | 0.000 | 0.000 | 0.000 |
| General Surgery Department, Section One | 0.000 | 540.411 | 0.000 | 0.019 | 0.000 | 1.108 | 0.000 |
| Orthopedics Department | 116.694 | 191.667 | 0.000 | 0.019 | 0.000 | 0.000 | 0.000 |
| Neurosurgery Department | 417.187 | 298.287 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Vascular Surgery Department | 0.000 | 293.343 | 0.258 | 0.073 | 0.000 | 1.412 | 0.000 |
| Cardiology Department, Section One | 0.000 | 1025.314 | 0.112 | 0.026 | 0.000 | 3.221 | 0.000 |
| Cardiology Department, Section Two | 0.000 | 688.999 | 0.032 | 0.118 | 0.000 | 1.205 | 0.000 |
| Critical Care Medicine Department | 0.000 | 0.000 | 0.025 | 0.181 | 0.000 | 0.368 | 0.000 |
| Gynecology Department | 0.000 | 823.072 | 0.000 | 0.036 | 0.000 | 0.000 | 0.000 |
| Emergency Department, Section Two | 0.000 | 467.415 | 0.000 | 0.147 | 0.000 | 1.110 | 0.000 |
| Nephrology Department | 64.669 | 0.000 | 0.000 | 0.054 | 0.000 | 0.000 | 0.000 |
| General Surgery Department, Section One | 0.000 | 110.476 | 0.037 | 0.016 | 0.000 | 1.724 | 0.000 |

incidence rate was 2.4%, indicating that the infection control output could continue to improve on the basis of existing inputs, but was already approaching the optimal infection control level.

From a single input-output indicator analysis of improvement, there was a high rate of input redundancy in hand hygiene compliance indicators in the departments of Gastroenterology, Nephrology, Orthopedics, General Surgery II, and Neurosurgery. Among them, the Neurosurgery Department had the highest rate of input redundancy in hand hygiene compliance indicators at 417.2%, whereas in the indicator of the consumption of infection control materials per inpatient, there was a high rate of input redundancy in 13 clinical departments, including General Surgery II, Orthopedics, Gastroenterology, Spinal Surgery, Hepatobiliary Surgery, and Vascular Surgery. Among them, the Cardiology Department had the highest rate of input redundancy, at 1025.3%; In the indicator of the consumption of infection control materials per inpatient, there was a high rate of input redundancy in the Intensive Care Medicine, Vascular Surgery, Cardiology, Hepatobiliary Surgery, General Surgery II, and Cardiology II departments. Among them, the Vascular Surgery department had the highest rate of input redundancy, at 0.3%; In the indicator of training and drill frequency, there was a high rate of input redundancy in 14 clinical departments including Intensive Care Medicine, Emergency Medicine II, Cardiology II, Vascular Surgery, and Spinal Surgery. Among them, the Intensive Care Medicine department had the highest rate of input redundancy at 0.2%. In the indicator of hospital infection case rates, the Cardiology Department had the highest inadequate output rate at 3.2%.

## Discussion

The DEA model has advantages in health economic evaluations and has gradually begun to be used to explore application methods in the field of hospital infection prevention and control. This study, based on data from 27 ward departments meeting inclusion criteria in 2022, utilized the DEA BCC model to analyze the efficiency of hospital infection management and input-output improvement in each clinical department. Through results-oriented approaches, departments can achieve higher levels of infection control efficiency and lower average infection control costs.

The DEA is a nonparametric efficiency evaluation method characterized by its independence from specific assumptions. Compared with traditional models such as linear regression and analysis of variance, the DEA model does not require conformity to certain assumptions such as a normal distribution or homoscedasticity. By simultaneously considering multiple input and output indicators, the DEA model comprehensively calculates the maximum output achievable through a unit input, making full use of the information available in clinical practice, and circumventing the limitations of singular indicator evaluations.[3] The output of the DEA model entails rankings obtained through a mutual comparison of various clinical departments, offering a qualitative outcome rather than a single index or numerical value, thereby rendering results more comprehensible and acceptable to hospital decision-makers and suitable for decision-making on multifaceted issues.[27] This research specifically focused on the analysis of input-output improvement in hospital infection management in clinical departments, aiming to enhance input efficiency and reduce hospital infection and multidrug-resistant bacteria detection rates. Employing a more flexible BCC model, this study provided a more precise efficiency evaluation than the traditional DEA model, because it was designed for output-oriented models with variable returns to scale. However, the BCC model requires a larger sample size than the traditional DEA model to minimize evaluation bias and ensure reliability.[28]

Among the 27 clinical departments, 12 (44%) were classified as highly effective in the DEA context, indicating that the input-output of these DMUs had reached a state of rational allocation. In contrast, 15 departments (56%) were found to be non-DEA effective, with room for improvement in the input-output efficiency. The diminishing returns to scale in the Department of Neurosurgery suggest a relatively large scale of input, necessitating adequate control of the scale and enhancement of departmental infection control management.

The DEA model provided data for improving infection control in clinical departments, such as identifying high levels of redundancy in consumption of infection control materials per inpatient. The relatively high infection control costs and low efficiency of certain departments indicate the need to correct inefficient links in the infection control chain, thereby reducing unnecessary resource wastage and costs. The redundancy rate of infection control material usage per inpatient was notably high in all departments, except for the Intensive Care Unit and Nephrology Department. It appears that investment in infection control materials did not effectively reflect the prevention of hospital infections and may involve wasteful practices. These findings should be discussed with clinical experts. The main redundant infection control material was hand disinfectant, with an increase in usage not only among medical staff due to the impact of the COVID-19 pandemic, but also significantly higher usage among patients and their caregivers during hospitalization, even leading to excessive use. This indicator suggests the need for clinics to more effectively implement patient education on hand hygiene, thereby enhancing infection control efficiency and quality of clinical departments. The input redundancy rate of hand hygiene compliance was also relatively high. The collection of this data is subject to a certain Hawthorne effect. In clinical practice, hand hygiene is the most effective and economical measure for infection control.[29] From the perspective of evidence-based infection control, the input redundancy rate of this indicator can be temporarily disregarded, and continuous quality improvement of hand hygiene measures should still be pursued.

On comparing the infection rates among medical institutions of a similar scale, it was observed that certain departments exhibited a high prevalence of infections. To reduce these rates, the Departments of Cardiology, Hepatobiliary Surgery, General Surgery Unit 2, Vascular Surgery, Department of Cardiology 2, Emergency Unit 2, General Surgery Unit 1, and Intensive Care Unit have the potential to further decrease the hospital infection incidence rate without altering the current input indicators. This necessitates collaborative efforts between clinical departments and hospital infection control personnel to identify infection risk points during clinical work, effectively implement infection control measures, and establish infection rate targets supported by data.

Huang et al[18] considered the amount of hand sanitizer received, hand hygiene compliance, and cleanliness compliance as input indicators and the hospital infection rate and positivity rate of multidrug-resistant bacteria as output indicators. The input indicators in this study detail infection control supplies in terms of the total amounts of hand sanitizers, hand soap, paper towels, disinfectant wipes, and chlorine-containing disinfectants received, taking into account the impact of the number of inpatients per unit to avoid the influence of departmental efficiency evaluation due to the high number of patients admitted. We plan to conduct further research to further refine the study methodology to include separate investigations of the internal and surgical departments. In addition, the infection rates at Class I surgical sites, rate of antibiotic prophylaxis in Class I surgical site infections, rate of catheter-related bloodstream infections, rate of ventilator-associated pneumonia, and rate of urinary tract infections related to urinary catheters will be included as output indicators, making the indicator design and infection control efficiency evaluation more precise.

Previous studies have shown that the allocation of medical staff and beds in the respiratory department of China's tertiary grade A public hospitals was DEA effective based on workload.[30] In this study, the infection control allocation in the respiratory department was also DEA strongly effective. As a key department and a high-risk infection department in tertiary grade A hospitals, the respiratory department is effectively configured both based on workload and infection risk. The clinical transformation of the research results can be carried out in two aspects: on the one hand, rectification can be made based on the personalized analysis of the DEA model of each department; on the other hand, the infection control measures and input indicators of DEA strongly effective departments can be referred to, guiding non-DEA effective departments with similar infection control risks to carry out infection prevention and control. The evaluation of hospital infection control efficiency using the DEA model only reflects the relative efficiency levels of each DMU without indicating the OE level of these clinical departments. It can also be used as a basis for ranking and rewards or punishments in practice (Figure 2).

## Limitations

The study acknowledges several limitations. The BCC model requires a larger sample size to reduce bias and enhance reliability. This study, however, was based on data from only 27 ward departments in 2022, which may limit the stability and generalizability of the results. The DEA model is highly sensitive to input and output data, and outliers or noise can lead to deviations in the results. For example, the usage of infection control materials may have been abnormally high due to special circumstances such as the COVID-19 pandemic, affecting the accuracy of the efficiency assessment. The efficiency assessed by the DEA model is relative, reflecting only the relative efficiency levels among DMUs rather than their absolute efficiency levels. This means that even if some departments are deemed efficient in the DEA assessment, their actual infection control effectiveness may still need further validation.

Additionally, while the study has tried to be comprehensive in selecting input and output indicators, there may still be omissions or inaccuracies. The DEA model assumes homogeneity among DMUs, which may not hold true in the actual hospital environment where departments differ significantly due to their professional characteristics, patient groups, and resource allocation. The output of the DEA model is a ranking obtained through mutual comparison among various clinical departments, providing qualitative results rather than a single numerical indicator. This may require further explanation and analysis to ensure that decision-makers can accurately grasp the specific reasons for efficiency differences and the direction for improvement. Finally, implementing improvement measures in inefficient departments may be challenging due to factors such as insufficient personnel, outdated equipment, or complex management processes, which may limit the application value of the assessment results from the DEA model (Figure 3).

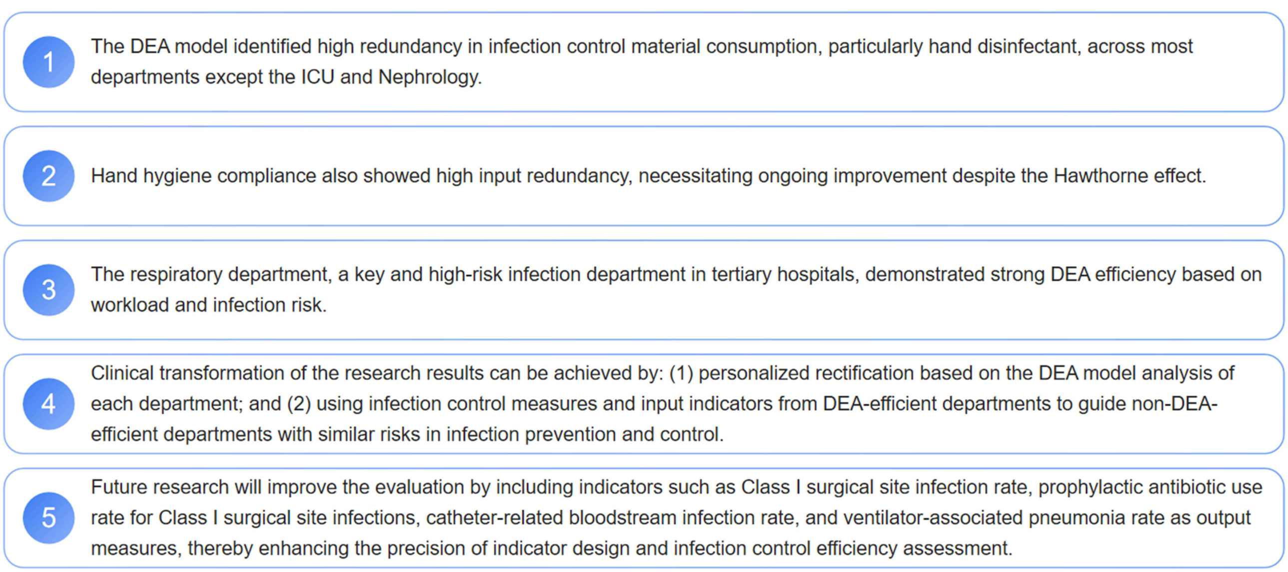


**Figure 2** The key findings of this study.

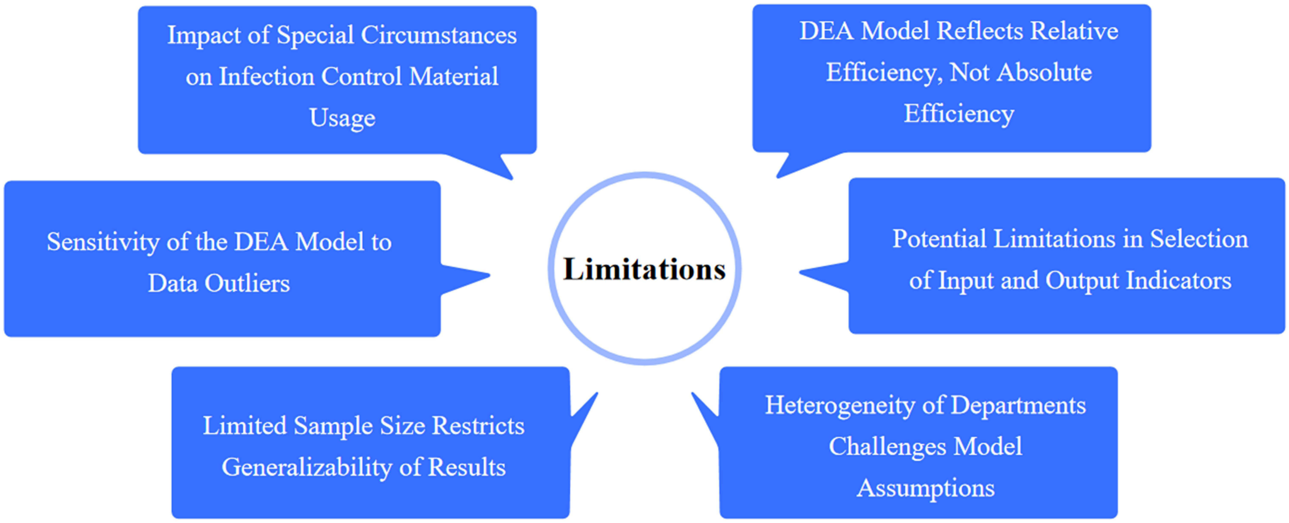


**Figure 3** The limitations of this study.

## Policy Implications

This study provided important insights for hospital management and the formulation of infection control policies by identifying strengths and areas for improvement in hospital infection control through DEA. The results emphasized the necessity of targeted resource allocation, with non-DEA-effective departments requiring prioritized distribution of personnel, equipment, and training resources to optimize the use of infection control resources and enhance overall performance. By comparing the efficiency of different departments, hospitals could identify and disseminate best practices from high-performing units, thereby improving the quality of infection control across the entire hospital. The study also offered a basis for policy-making by identifying departments with increasing or decreasing returns to scale, allowing hospitals to develop targeted strategies to support the expansion of efficient departments or address efficiency issues in less efficient ones. In summary, this study offered practical suggestions for optimizing infection control efficiency, ultimately contributing to improved patient safety and healthcare quality.

## Conclusion

Through the analysis conducted using the BCC model, hospital infection control staff identified focus areas for improving input-output efficiency within non-DEA-effective clinical departments. Using DEA for assessment can provide managers with valuable insights, pinpointing avenues for enhancing efficiency and optimizing resource utilization. This endeavor aids in improving the performance of infection control, fostering both competition and collaboration among departments, thereby enhancing the overall quality and efficiency of the hospital.

While this study has achieved certain results, it still has limitations such as a small sample size, high data sensitivity, inability to reflect absolute efficiency, potential limitations in indicator selection, and limited interpretability of results. Future research will expand the sample size to reduce assessment bias and enhance the generalizability of the results, while incorporating Benchmarking and Ranking Technique to improve the interpretability of the results. Moreover, improved DEA models, such as the Bootstrapping model and the Metafrontier model, will be adopted to further enhance the accuracy and reliability of the research.

In the evaluation of nosocomial infection management efficiency, future research may consider employing methods such as SFA and Cross-Efficiency Evaluation (CREE). SFA introduces random error terms, allowing for statistical significance testing, which can provide more stable efficiency scores and distinguish between technical inefficiency and random noise. This is particularly important for accurately assessing the efficiency of hospital infection management. CREE combines self-assessment and peer-assessment, offering a more comprehensive ranking of DMUs and avoiding unrealistic weights that may occur in traditional DEA. The integration of these methods can provide a more nuanced understanding and improvement of hospital infection management efficiency.

## Data Sharing Statement

Due to restrictions imposed by the hospital regarding the management of hospital infection control data, the dataset is not publicly available online. However, interested researchers may obtain access to the data by contacting the corresponding author. It is our commitment to ensure that the data can be shared responsibly and in accordance with the privacy and ethical guidelines set forth by the hospital and relevant regulatory bodies.

## Ethical Statement

Ethical approval was not required for this study. The data utilized were derived from anonymized, aggregated records of hospital wards and departments from January to December 2022, focusing solely on infection prevention and control indicators. No individual patient data were accessed, and no human subjects were involved.

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## Disclosure

The authors declare that they have no conflicts of interest to this work.

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