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Quantitative Study on the Social Benefit of Medical Devices

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Abstract: The performance status of large medical device is one of the core driving forces behind hospital operations and development, and its importance is self-evident. It involves the economic benefits of hospitals-by improving diagnostic and treatment efficiency, reducing costs, and directly contributing to fiscal revenue, but it also profoundly affects the social benefits of hospitals. These social benefits include improving the quality of medical services, increasing patient satisfaction, and building public trust, all of which contribute intangible value. These positive social benefits effectively attract more patients, which in turn becomes a potential driver for long-term hospital development and a growth point for economic benefits. This paper innovatively applies the Fuzzy Analytic Hierarchy Process (FAHP) to address the challenge of quantifying the social benefits of large medical device. It achieves a comprehensive and precise evaluation of both economic and social benefits. The introduction of this method provides hospital device managers with a more thorough and in-depth insight into device performance, enabling data-driven decision-making and more refined and scientific management. Through data-driven management optimization, hospitals can further enhance operational efficiency, strengthen competitiveness, provide higher quality and more efficient medical services to patients, and lay a solid foundation for their own sustainable development.

Keywords: Fuzzy Analytic Hierarchy Process; Social Benefit; Medical Devices; Performance Evaluation

1. Research Background

The development of modern hospitals must ensure both high quality and efficiency in hospital operations while remaining centered on the interests of the people. This balance is crucial. From the current policy direction, the country places high importance on the social benefits generated by healthcare institutions. Achieving higher public satisfaction and enhancing people's sense of well-being are critical for maintaining social harmony and stability.

As a vital component of the healthcare system, public hospitals must not only pursue high-quality development but also remain focused on public health. Ensuring the public welfare aspect of basic medical and health services is maintained reflects the nation's strong commitment to healthcare development and deep concern for the safety and health of its citizens.

2. Social and Economic Benefits of Hospitals

1. The social benefits of hospitals are primarily reflected in their effective use of healthcare resources to provide high-quality diagnostic and treatment services to the public, thereby improving the quality of life and health standards. In this process, hospitals inevitably generate a range of social impacts, which constitute their social benefits. These benefits not only highlight the hospital's contributions to society but also reflect its social responsibility and value as a public service institution.

2. Economic benefits are the cornerstone of a hospital's survival and development, directly influencing its operational status and future growth [1-5]. However, social benefits also hold a crucial position, representing both the hospital's responsibility to society and its own image and reputation.

3. Economic and social benefits in hospital management exhibit a relationship that is both contradictory and unified [6]. Both of them are interdependent and mutually reinforcing, forming two indispensable aspects of hospital management.

Therefore, while pursuing economic benefits, hospitals must place significant emphasis on enhancing social benefits to achieve a

harmonious coexistence and mutual development of both dimensions.

3. The Role of Large Medical Devices in Hospitals

In public hospitals, large medical device holds a crucial position, reflected in the following aspects:

1. In the context of DRGs (Diagnosis Related Groups) payment mechanisms and centralized procurement of medical supplies, revenue from large medical device is one of the few revenue-generating methods available to hospitals. It can even impact the survival and development of hospitals.
2. Large medical device, such as CT (Computed Tomography) and MRI (Magnetic Resonance Imaging), can significantly improve medical quality. Advanced device leverages its technological advantages to provide detailed reports and high-resolution images, offering doctors precise and efficient diagnostic tools. This enables more accurate understanding of patients' conditions and the development of precise treatment plans, greatly enhancing the quality of medical care.
3. With the rapid development of information technology, the data from large medical device are now integrated into major hospital systems, such as PACS (Picture Archiving and Communication Systems). This integration automates and enhances the efficiency of many medical examinations and treatments, reducing patient wait times, improving report accuracy, and alleviating the workload of medical staff.
4. Although the initial purchase and maintenance costs of large medical device are high, these devices can significantly reduce long-term hospital costs. They enable the completion of a large number of examinations and treatments in a short period, avoiding additional costs caused by diagnostic delays. Additionally, rapid and accurate diagnosis helps save on treatment costs related to misdiagnosis or delayed treatment.

Thus, the proper use of large medical device can enhance hospital operational efficiency, provide more accurate and efficient diagnostic and treatment services, and bring significant economic benefits. At the same time, the high efficiency and accuracy of this device can improve patient care experiences, enhance medical quality, and optimize the allocation and use of medical resources, resulting in substantial social benefits for hospitals. Therefore, social and economic benefits complement and drive each other, jointly promoting the high-quality development of hospitals. However, while economic benefits are relatively easy to calculate, social benefits are more challenging to quantify. Understanding the indirect revenue generated by social benefits of medical device is crucial for hospital managers to achieve scientific and rational allocation and management of medical devices.

4. Challenges in Evaluating the Social Benefits of Medical Device

Evaluating the social benefits of medical device presents the following challenges:

1. Uncertainty in Evaluation Criteria: The evaluation of social benefits often involves multiple aspects, such as examination comfort, positive detection rates, examination speed, and maintenance frequency. These criteria are often vague, with some indicators being highly subjective and others exhibiting significant randomness, making them difficult to measure with specific quantitative metrics. Additionally, variations in interpretation and evaluation due to differences among evaluators can lead to a lack of standardized evaluation criteria.
2. Broad Data Scope: Social benefit evaluation requires collecting a large amount of relevant data from various perspectives. This data is often dispersed among medical staff and patients, making it challenging to gather. Moreover, processing and analyzing this data is different from economic indicators, necessitating specialized knowledge and skills from the evaluator.
3. Variable Influencing Factors: The evaluation of social benefits is affected by various factors, including technological advancements, the skill level of operators, and the cultural background of patients. Changes in these factors can introduce uncertainty and instability into the evaluation results.
4. Limitations of Evaluation Methods: Existing methods for evaluating social benefits have certain limitations, such as oversimplification in quantitative assessments and subjectivity in qualitative evaluations. Selecting appropriate evaluation methods and techniques to ensure the accuracy and reliability of the results is an ongoing challenge that requires continuous exploration and practice.

5. Research Status at Home and Abroad

Since social benefit evaluation indicators are generally non-monetary and cannot be measured in monetary terms like economic benefit indicators, the depth, breadth, and standards of research on social benefits are not as advanced as those for economic benefits. Scholars both domestically and internationally began researching social benefits relatively late, and the relevant theoretical systems and research methods are still underdeveloped. The analysis methods for the social benefits of large medical device in hospitals are also evolving, and many aspects remain inconclusive. Currently, the most common method that integrates social benefit analysis in medical device performance evaluation is the comprehensive net present value cost-benefit analysis method [7].

This method evaluates the overall benefit of medical device by calculating the unit input cost (100 yuan) and the comprehensive net present value cost-benefit (NPVCB) over a unit period (1 year). The specific model is as follows:

$$\mathrm{NPV_{CB}} = \frac{(\text{Economic benefit weight+social benefit weight})\text{Present value of net cash flows}}{\text{Value of equipment}} \times 100\ \text{Yuan} \quad (1)$$

where, the economic benefit weight+social benefit weight=1

The model posits that the value created by device should be divided into two components: one part of the benefit is derived from social benefits (such as a positive patient experience encouraging repeat visits). Therefore, the model adjusts the net present value within the evaluation period by using economic benefit weights and social benefit weights to achieve a comprehensive analysis of medical device benefits. For example, if the weights for economic and social benefits are set at 0.7:0.3, and there are two pieces of device (e.g., one CT and one diagnostic device) with a total net cash flow of 10,000 yuan, the social benefit created would be 10,000 × 0.3 = 3,000 yuan. Since social benefits are generated overall by the hospital, and each piece of device contributes differently to the hospital's social benefits, the challenge is to redistribute the 3,000 yuan of social benefit between the CT and diagnostic device. The key point is to determine the weight for the distribution of social benefits among the device.

In recent years, the fuzzy analytic hierarchy process (FAHP) has started to be used for quantitative analysis of social benefits generated by projects in various industries. Among various subjective analysis and evaluation methods, the Analytic Hierarchy Process (AHP) offers significant advantages. It effectively helps in making decisions on many qualitative issues that are difficult to quantify. Traditional AHP involves constructing judgment matrices with minimal consideration of the subjectivity of decision-makers, and the consistency check of judgment matrices is complex and cumbersome, with some debate about the scientific validity of consistency rules. To address these limitations, scholars have introduced fuzzy consistency matrices into AHP analysis. This integration of AHP with fuzzy mathematical theory, known as Fuzzy Analytic Hierarchy Process (FAHP), effectively addresses the subjective ambiguity in decision-making [8,9].

6. Calculate Social Benefit Weight with FAHP

Let's continue using the CT and diagnostic device as examples to construct a hierarchical model (Figure 1).

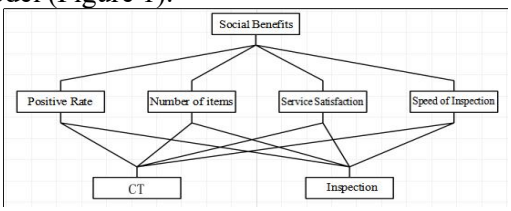

Figure 1. Hierarchical Model of Social Benefits

This study sets social benefits as the overall goal. The criteria layer used for analysis and judgment is established based on the current actual situation of the hospital. The indicator system for social benefits can be divided into two parts: subjective indicators and objective indicators. The subjective indicators are primarily assessed through the design of questionnaires, where different stakeholders such as doctors, technicians, researchers, and patients are invited to provide scores. The objective indicators are obtained through data from medical management systems, HIS (Hospital Information System), research management systems, etc., such as device utilization rates and positive test rates. The combination of these two parts forms the intermediate layer (criteria layer) in the Analytic Hierarchy Process. The final alternative layer consists of the CT and diagnostic device.

Based on the model, design and distribute the questionnaire (Table 1), and summarize the scores from the questionnaire to obtain the scores for each element at different layers.

Table 1. Questionnaire

Social benefit									
	1 point	2 points	3 points	4 points	5 points	6 points	7 points	8 points	9 points
Positive Rate	☐	☐	☐	☐	☐	☐	☐	☐	☐
Number of items	☐	☐	☐	☐	☐	☐	☐	☐	☐
Service atisfaction	☐	☐	☐	☐	☐	☐	☐	☐	☐
Speed of nspection	☐	☐	☐	☐	☐	☐	☐	☐	☐
Social Benefits-Positive Rate									
	1 Point	2 Points	3 Points	4 Points	5 Points	6 Points	7 Points	8 Points	9 Points
CT	☐	☐	☐	☐	☐	☐	☐	☐	☐
Inspection	☐	☐	☐	☐	☐	☐	☐	☐	☐
Social Benefits-Number of Items									
	1 Point	2 Points	3 Points	4 Points	5 Points	6 Points	7 Points	8 Points	9 Points
CT	☐	☐	☐	☐	☐	☐	☐	☐	☐
Inspection	☐	☐	☐	☐	☐	☐	☐	☐	☐
Social Benefit-Service Satisfaction									
	1 Point	2 Points	3 Points	4 Points	5 Points	6 Points	7 Points	8 Points	9 Points
CT	☐	☐	☐	☐	☐	☐	☐	☐	☐
Inspection	☐	☐	☐	☐	☐	☐	☐	☐	☐
Social Benefits-Speed of Inspection									
	1 Point	2 Points	3 Points	4 Points	5 Points	6 Points	7 Points	8 Points	9 Points
CT	☐	☐	☐	☐	☐	☐	☐	☐	☐
Inspection	☐	☐	☐	☐	☐	☐	☐	☐	☐

Based on the scores, construct the judgment matrix, calculate the weight Indicator (WI) for each factor, and perform the consistency index (CI) test.

The final calculation process and results are as follows (Table 2-Table 8).

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad (2)$$

Table 2. Weighting Matrix: Social Benefits

	Positive Rate	Number of items	Service Satisfaction	Speed of Inspection	Weight (wi)
Positive Rate	0.5	0.7	0.4	0.7	0.3
Number of items	0.3	0.5	0.4	0.8	0.25
Service Satisfaction	0.6	0.6	0.5	0.6	0.3
Speed of Inspection	0.3	0.2	0.4	0.5	0.15

Consistency Index CI =0.0688

Table 3. Weighting Matrix: Positivity Rate

	CT	Inspection	Weight (wi)
CT	0.5	0.6	0.6
Inspection	0.4	0.5	0.4

Consistency Index CI =0

Table 4. Weighting Matrix: Number of Items

	CT	Inspection	Weight (wi)
CT	0.5	0.3	0.3
Inspection	0.7	0.5	0.7

Consistency Index CI =0

Table 5. Weighting Matrix: Service Satisfaction

	CT	Inspection	Weight (wi)
CT	0.5	0.4	0.4
Inspection	0.6	0.5	0.6

Consistency Index CI =0

Table 6. Weight Matrix: Check Speed

	CT	Inspection	Weight (wi)
CT	0.5	0.4	0.4
Inspection	0.6	0.5	0.6

Consistency Index CI =0

Table 7. Middle Layer Weight Table

Node	Global Weight	Sibling weight
Positive Rate	0.3	0.3
Number of items	0.25	0.25
Service Satisfaction	0.3	0.3
Check speed	0.15	0.15

Table 8. Conclusion Table (Social Benefit Weighting of Devices)

Base Element	Concluded Value (Weight)
CT	0.435
Inspection	0.565

7. Calculation of NPV_{CB}

Taking the actual business revenue data for large device such as CT and biochemical immunology lines from a tertiary hospital in Nantong City in 2023 as an example, with the economic benefit and social benefit ratio set at 0.7:0.3, the social benefits are redistributed according to the social benefit weights calculated by the fuzzy analytic hierarchy process (Table 9):

Table 9. Allocation of Social Benefits

Devices:	Original Value	Present value of net cash flow	Return on Assets	Economic benefit proportion 0.7	Proportion of social benefits 0.3	Social benefit weight	Actual social benefit
CT	6500000	5736042.72	88.24%	4015229.90	1720812.82	0.435	1391034.26
Biochemical immunology line	5950000	4923223.67	82.74%	3446256.57	1476967.10	0.565	1806745.66
Total		10659266.39		7461486.47	3197779.92	1	3197779.92

Calculate NPV_{CB} indicator based on the redistributed social benefits:

NPV_{CB} (CT)=(4015229.90+1391034.26)/6500000×100=83.17

NPV CB (Biochemical immunology line) =(3446256.57+1806745.66)/5950000×100=88.28

Summary Results (Table 10):

Table 10. Calculation of Comprehensive Benefits of Device

Device:	Original Value	Economic benefits	Actual social benefit	Total benefits	NPV_{CB}
CT	6500000	4015229.90	1391034.26	5406264.16	83.17
Biochemical immunology line	5950000	3446256.57	1806745.66	5253002.23	88.28
Total		7461486.47	3197779.917	10659266.39	

Through calculations, it can be seen that, from the perspective of traditional performance indicators such as return on assets, the CT yields higher returns. However, when considering social benefit factors, the diagnostic (biochemical immunology line) brings higher overall benefits to the hospital. The starting point for evaluating devices performance affects the final results [10,11].

8. Conclusion

1. Evaluating the performance of large medical device from multiple dimensions is of significant importance. Traditional financial metrics are key standards for measuring device performance, but they may not fully reflect the true value of the device. In the healthcare industry, which places a high value on reputation, social benefit indicators better reflect patients' trust or loyalty towards the hospital and more directly indicate whether the hospital's operations are healthy.

2. Although CT device might show superior performance in terms of return on assets, the diagnostic line offers greater overall benefits to the hospital by improving diagnostic speed, reducing wait times and misdiagnosis rates, and enhancing the overall patient experience. These advantages may indirectly translate into higher patient satisfaction, better reputation, and long-term financial stability.

3. In the long run, device that significantly improves hospital operational efficiency and patient health outcomes may be more valuable than device with higher short-term financial returns. Hospital managers should consider long-term impacts in decision-making rather than focusing solely on short-term financial metrics.

4. In situations with limited resources, the results of comprehensive device performance analysis can help hospitals understand the true contribution of each type of device to hospital operations, assisting management in making more informed investment decisions.

9. Discussion

1. The factors affecting social benefits are numerous and highly subjective, making it a complex and difficult evaluation method to quantify directly. However, the Fuzzy Analytic Hierarchy Process (FAHP) can transform these hard-to-quantify issues into a multi-level single-objective problem, and obtain specific quantitative results through mathematical calculations, thus addressing the challenge of quantifying social benefits.

2. The Fuzzy Analytic Hierarchy Process treats

the research object as a whole system, organizing the influence of various factors on the research object according to a hierarchical structure. The impact of each factor at different levels on the final result is quantified, making the decision-making process clearer and more precise, which ensures the comprehensiveness and accuracy of the evaluation.

3. The Analytic Hierarchy Process is particularly suitable for evaluating the social benefits of large medical device. It overcomes the shortcomings of traditional medical device performance evaluation systems where social benefit evaluation and economic benefit evaluation are independent and cannot be integrated. This allows hospital managers to clearly assess the economic returns brought by social benefits, providing comprehensive and accurate control over device performance evaluation and offering valuable insights for device procurement and management.

4. By using FAHP to address the challenges of quantifying social benefits and integrating economic and social benefits through the comprehensive net present value cost-benefit ($\mathrm{NPV_{CB}}$), the overall performance of the device is presented in specific numerical terms. This resolves the issues of performance evaluation between different types of device. The $\mathrm{NPV_{CB}}$ standardizes cost-benefit analysis to a hundred yuan basis, enabling horizontal comparisons of the comprehensive performance of various hospital device, providing a powerful analytical tool for performance analysis and a support point for refined hospital management.

5. Compared to subjective and vague evaluation methods, the persuasiveness of quantitative social benefit indicators is stronger. Quantified social benefits are advantageous for the application of big data analysis models in hospitals, helping to refine the medical device performance evaluation system, reducing subjectivity and bias in the evaluation process, and improving fairness and accuracy, thus promoting continuous improvement and optimization.

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