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Original Research Article

A Decision Support System for Rational Deployment of Medical Equipment Based on Real-world Data

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ABSTRACT

Objectives: To inform judgments about the efficient and rational deployment of medical equipment in hospitals and give decision support.

Methods: The information system for rational deployment of medical equipment (MERDIS) is based on ASP.NET MVC framework and designed with SQL Server database and C# language. The analysis methods are based on clinical pathway demand and multiple regression data statistics. It uses big data collected from hospitals, including current equipment deployment, clinical pathways, and other basic information, to calculate and provide each hospital with a recommended equipment deployment.

Results: By analyzing the data of 52 hospitals through the MERDIS system, it is convenient, accurate, and intuitive to get the rational deployment plan, and suggestions of different types of hospitals affected by different factors can be given conveniently, accurately, and intuitively.

Conclusions: The MERDIS system's design provides the basis for the subsequent development of medical equipment macro data management. In the process of continuous improvement and supplementing of data, the software model will become more and more accurate and reliable.

Keywords—*Rational deployment of medical equipment, Big data, Decision support, ASP.NET.*

INTRODUCTION

At present, medical and health resources are still scarce resources in China.[1–3] The problem of inappropriate deployment of medical equipment in hospitals is a significant issue. Irrational and excessive purchase or insufficient deployment of large-scale medical equipment is widespread. However, there are limited studies on deploying and utilizing large-scale medical equipment.[4–15] This paper aims to design a system that can enter the general information to provide a rational recommendation for the rational deployment of medical equipment in hospitals.

There are multiple advantages to addressing and solving the problem of irrational deployment of medical equipment in hospitals. Such benefits include, among others, an increase in the utilization efficiency of medical equipment resources, improving the care and health of patients, reducing medical appointment waiting lists for diagnosis and treatment, and ensuring that newly established hospitals are adequately and efficiently equipped. As such, many benefits arise for patients, health practitioners, and hospital management in establishing an effective medical equipment deployment planning system. This is particularly important in public hospitals where resources are limited, and capital expenditure needs to be carefully managed.

The deployment of medical equipment is typically the remit of the hospital equipment department. Indeed, there is a body of domestic literature on the methods of medical equipment deployment. However, such literature tends to be limited to a certain hospital and does not consider the hospital as a unit.[4,5] Furthermore, foreign research explicitly focuses on emergency medical equipment control methods.[3] Either for the special situation of medical resources allocation analysis[7,8], to solve this problem ethically[9], or for the allocation of scarce medical resources research. There are many domestic pieces of research on the purchase decision analysis of medical equipment[10–13], but they are not based on much actual data research. There is a gap in the literature as it has not yet considered the potential role of detailed and complex statistical investigation in equipment deployment.

The information system for rational deployment of medical equipment, or MERDIS for short, is developed with C# language, and the main framework is ASP.NET MVC. This study investigated the basic information of 52 hospitals in Shanghai and other provinces to provide a data basis. The investigated hospitals include various types. The MERDIS analyses the above data in the database and gives the corresponding deployment plan recording to the hospital parameters.

METHODS

Functional Requirements Analysis

The deployment quantity of medical equipment should be directly affected by the frequency of such equipment, and the frequency of equipment is directly affected by the frequency of surgeries and visits in the hospital. At the same time, the hospital's level, built-up area, and physical resources cause differences in the frequency of surgeries and visits. The annual income of the hospital directly reflects the differences in the frequency of operations and visits among hospitals. Therefore, the deployment method can be designed based on the above information. The different influence factors were analyzed and processed by collecting the above data. Then, a rational deployment plan of medical equipment in different hospitals is provided to ensure the rational deployment plan of medical equipment in the hospital.

The main users of MERDIS are the hospital equipment managers or the relevant personnel of the hospital procurement center. Ordinary users have the authority to log in, register, enter information, query the deployment plan, and other functions. Based on the functions of ordinary users, administrators have the authority to manage user information, hospital information, information check, and modification. The information users enter includes the hospital's basic influencing factors, the deployment information of medical equipment, and the clinical pathway information. Figure 1 is a usage case diagram of the MERDIS.

System Design Ideas and Architecture

The key technology on which the system is based is the ASP.NET MVC framework. ASP.NET MVC is a framework for building scalable, standards-based web applications using well-established design patterns and the power

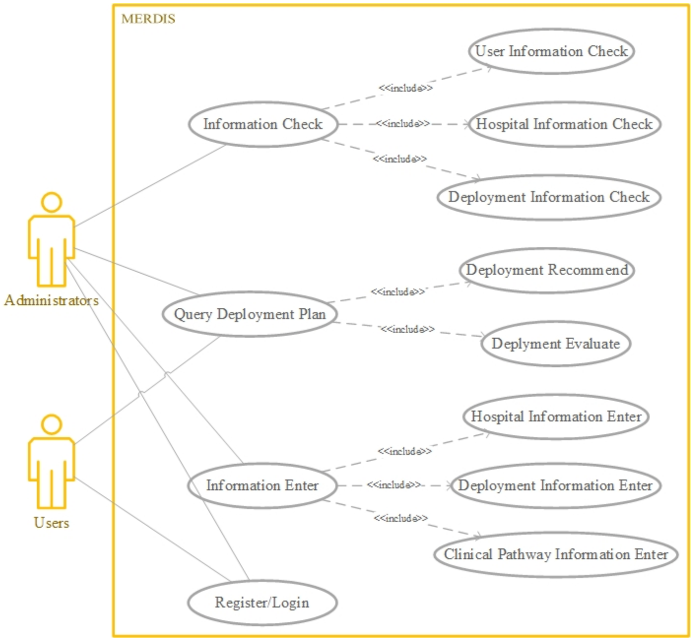

FIGURE 1. Usage case diagram of the MERDIS.

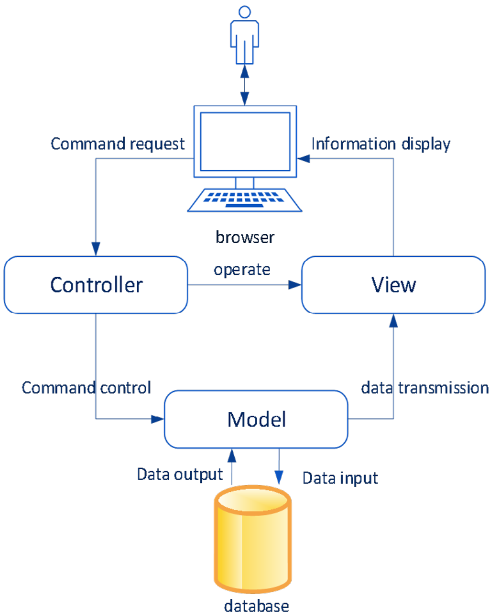

FIGURE 2. Relationship of MVC parts.

of ASP.NET and the .NET Framework. The MVC-based framework is divided into model, view, and controller. This framework divides data and view independently and loses the coupling between modules. The browser sends the client request to the front-end controller in this framework. The controller forwards the request according to the configuration file, and the back-end controller interacts with the processor mapper. After determining the view corresponding to the request, the data model is extracted from the database through the data interaction layer and processed. Finally, the model and view of the execution result are rendered, and the interface view with data is returned to the user. This mode fully applies each component in the whole operation process and realizes the traits of dynamic modular update of the system.[14–21]

Take data transmission, the deployment information of the hospital medical equipment used for various analyses in the system is stored in the database, the client requests the deployment recommendation from the system in the browser, the controller receives the operation instruction, and sends the data output command to the database. The corresponding part of the data in the database is taken out through the data model and then calculated by a series of algorithms in the controller. Finally, the recommended or theoretical minimum deployment quantity should be fed back to the user through the view (display layer). Figure 2 is the diagram of MVC parts.

Function Module Design

The main application objects of MERDIS are medical equipment, and the main users are hospital staff. The target aim is to recommend and evaluate the deployment of medical equipment. For ordinary users, they should register before logging into the system. As the hospital data is highly confidential, for information security, the registration information should be checked by the administrator first, and then the users can log in to the system. After logging in, users can query deployment recommendations, query deployment evaluation, and upload hospital information, medical equipment information, and clinical pathway information. Administrator users can process user and hospital information in the database based on the functions that ordinary users can achieve. At the same time, the information check function is added to check and approve the newly uploaded user information and hospital information. The abnormal information of users and hospitals is rejected or deleted, and only the normal data can be input into the database. Figure 3 shows the functional flowchart of MERDIS.

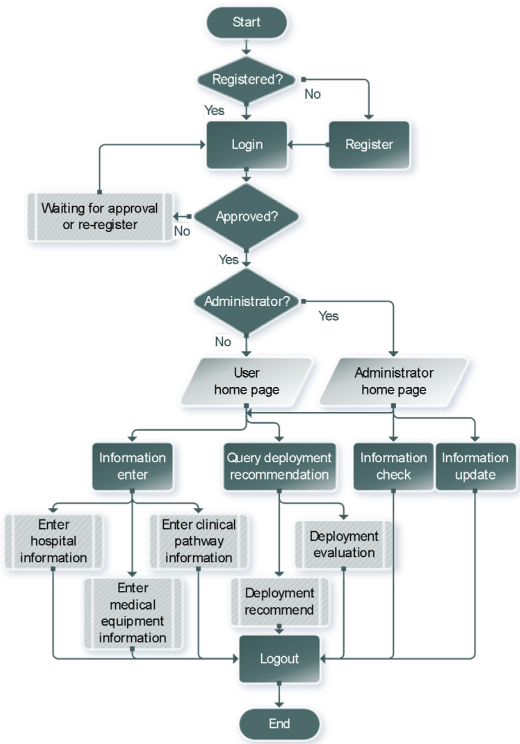

FIGURE 3. The functional flowchart of MERDIS.

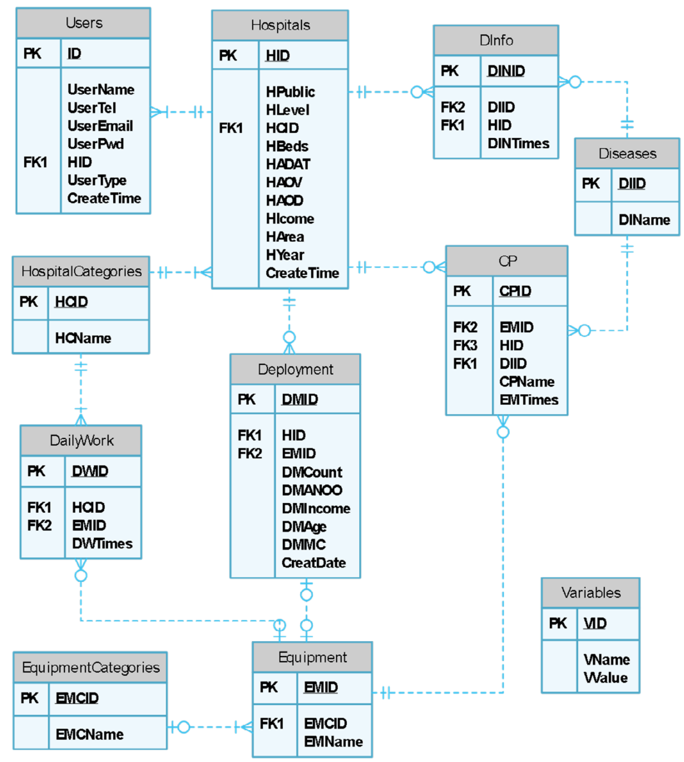

FIGURE 4. Database diagram of MERDIS.

Database Design

The main entities of MERDIS include users, hospitals, equipment, and diseases. Each entity is a table in the database. The relational table between the hospital and medical equipment is the "deployment" table, and the relational table between "disease type" and "hospital" is the "DInfo" table, which is used to represent the frequency of diagnosis and treatment of hospital diseases. For disease types, equipment, and hospitals, the relationship between the three became a table "CP", which stores clinical pathway information. What's more, to facilitate the representation and save storage space, a "hospital-categories" table was set up for hospital classification, an "equipment-categories" table was set up for equipment classification, and a "daily work" table to record the daily workload of different types of hospitals to different kinds of equipment, a "variables" table was set up to store calculation information. Figure 4 is the database class diagram of MERDIS, through which we can intuitively understand the logical relationship between various table items in the database.

Deployment Method Based on Clinical Pathway

The basic information of the 52 hospitals surveyed includes the attributes of the hospital, category, number of beds, the annual number of surgeries, the number of doctors, the annual medical income, and the building area of the hospital. The information on the clinical pathway includes the disease type, the medical equipment used in each pathway, the usage times of the equipment in each pathway, and the annual implementation times of each pathway. The annual demand of the clinical pathway is calculated first. Based on the clinical pathway data of a hospital in the database, according to the capacity of the equipment, the annual clinical pathway demand for each kind of medical equipment in each hospital can be analyzed. Because the clinical pathway on file in the hospital cannot cover all kinds of diseases, the proportion of the operational volume of the clinical pathway in the total operation quantity can be calculated according to the hospital's annual operation quantity. The actual operation quantity of the hospital is approximately replaced by the total number of clinical pathways used divided by this proportion to improve the accuracy of the theoretical minimum deployment value. The formula is as follows:

$$R_{p,q} = \frac{H}{\sum_{j=1}^{k} M_j} \cdot \left(\sum_{i=1}^{k} N_i \, M_i \right) \tag{1}$$

where, "R", "M", "N", "H", "p", "q", and "k" are integers greater than or equal to 1. And "M" is the annual usage times of the clinical pathway, "H" is the annual operation quantity of the hospital, "N" is the usage times of a certain kind of equipment to be studied in the clinical pathway (calculated according to the theoretical times of examinations), "k" is the total quantity of clinical pathways in the hospital, "$R_{p,q}$" is the annual clinical pathway demand of equipment "q" in the hospital "p".

Next, the equipment capacity of each kind of equipment is estimated. Due to the influence of the environment, work process, service life, maintenance times, and other factors, the working capacity of medical equipment in the hospital is different. This method, according to clinical experience, estimates the average usage capacity of a certain type of equipment—"annual saturated working capacity" (calculated as "daily saturated workload (times) × annual start-up days") in the form of "S". It is worth noting that the daily saturated workload here refers to the maximum workload of the equipment under moderate working conditions rather than the continuous working capacity.

Finally, the theoretical minimum deployment quantity of the equipment is estimated. For the equipment to be studied, the minimum theoretical deployment of the equipment can be obtained by dividing the annual clinical pathway demand "R" by the annual saturated working capacity "S". As:

$$T_{p,q} = \frac{R}{S} \tag{2}$$

where $T_{p,q}$ is the theoretical minimum deployment quantity of equipment "q" in the hospital "p". Here, the value of T refers to the minimum number of deployment quantities to meet the normal completion of the hospital's in-patient operation, rather than the most rational number of the deployment.

Deployment Method Based on Big Data

Big Data analysis refers to advanced and efficient data mining and machine learning techniques applied to a large amount of data. Research work and results in big data analysis are continuously rising, and more and more new and efficient architectures, programming models, systems, and data mining algorithms are proposed.[21–23] In addition to the clinical pathway, this study also investigated the deployment of medical equipment in hospitals, including the quantity, grade, annual frequency of tests, annual income, service time, and maintenance cycle of certain medical equipment in each hospital. At the same time, nine independent variables such as the attribute of these hospitals, annual operation quantity, medical income, number of beds, and built-up area were also investigated as the influencing factors of medical equipment deployment. Based on the big data of these hospitals, the recommended deployment plan of medical equipment in a hospital can be given on the premise that the medical equipment of all the hospitals investigated is rationally deployed. The Least Square Method is used to calculate the multiple regression equation in the following format:

$$T = a_0 + a_2 x_1 + a_2 x_2 + \cdots + a_n x_n \tag{3}$$

where a_i is the coefficient, x_i is the basic parameter value, n is the number of impact factors, and T is the recommended deployment quantity based on big data. After each calculation, the regression coefficient is stored in the database to facilitate the next calculation. This deployment method mainly applies to newly established hospitals or hospitals preparing for consultation.

Other Influencing Factors

In this study, we can potentially enhance the deployment of medical equipment by integrating three key factors: average length of stay (ALOS), outpatient visits, and diagnosis procedure numbers. These factors have been shown to significantly influence the demand for medical resources.[24–28]

Calculation of ALOS: ALOS is a critical indicator that reflects the hospital's capacity usage and helps predict the demand for in-patient-related medical equipment. The formula used is as follows:

$$\text{ALOS} = \frac{\sum_{i=1}^{n} \text{LOS}_i}{n} \tag{4}$$

where LOS_i is the length of stay for patient i, and n is the total number of patients. According to studies, ALOS directly correlates with the equipment needs of hospitals with longer in-patient stays.[24,25,28]

Prediction of Outpatient Visits: Outpatient visits are essential for predicting the demand for outpatient medical equipment. We use regression analysis to forecast future outpatient visits based on historical data:

$$\widehat{Y}_t = \alpha + \beta_t + \epsilon_t \tag{5}$$

where $\widehat{Y}_t$ is the predicted outpatient visits, α is the intercept, β is the trend coefficient, and ϵ_t represents the error term. This model was influenced by previous studies that emphasize the importance of outpatient volume in medical resource allocation.

Diagnosis Procedure Numbers: Diagnosis-related procedures require different types and quantities of medical equipment. We model this as a linear programming optimization problem, considering the demand for each procedure type and the available hospital resources. The optimization model is as follows:

$$\text{Minimize} = \sum_{i=1}^{m} \sum_{j=1}^{k} c_{ij}\, x_{ij} \tag{6}$$

where c_{ij} is the cost associated with assigning equipment j to procedure i, and x_{ij} is the number of equipment units assigned to each procedure. This method is derived from existing models that allocate medical resources efficiently based on diagnostic needs.[25–28]

The final optimization model combines ALOS, outpatient visits, and diagnosis procedure numbers to allocate resources dynamically. The goal is to minimize costs while satisfying the demand for each hospital's medical equipment based on real-time data.

RESULTS

After the user logs into MERDIS, the system will obtain the corresponding user's information, including the name, the hospital where they work, and the user type, and then display the user information under the function bar of the home page, as shown in Figure 5 (taking the administrator home page as an example). At the top of the home page is the function bar. For ordinary users, there are new hospital information imports, new equipment information imports, contact information, and logouts. On this basis, administrator users have user information management, hospital information management, and information check. The homepage has three main functions: deployment recommendation, evaluation, and settings. The deployment recommendation is to query the newly established hospital's medical equipment deployment plan by giving this hospital's basic information. Deployment evaluation evaluates the current deployment of medical equipment in the hospital, analyzes whether the deployment plan is rational, and offers suggestions. Users can click "home page" to return to the main interface during use.

Take the deployment of CT (64 detectors) and MR (1.5T) in a first-class hospital of Obstetrics and gynecology as an example. The basic information and deployment of the two medical devices in the hospital are shown in Tables 1 and 2.

According to the data in Tables 1 and 2, formula (1) can be used to calculate the theoretical annual clinical pathway demand of CT (64 detectors) and MRI (1.5T), and then formula (2) can be used to calculate the theoretical minimum deployment number based on the clinical pathway.

For example, the theoretical minimum deployment number of CT (64 detectors):

$$T = \left(\frac{65108}{11881} \times 2714\right) / (120 \times 250) = 0.4958$$

FIGURE 5. Deployment evaluation page.

TABLE 1. Clinical data statistics of Shanghai First Maternity and Infant Hospital in 2019.

Hospital Level	Hospital Type	Operation Quantity (times)	Annual Clinical Pathway Usage (times)
First-class	Maternity Hospital	65108	11881

TABLE 2. Usage of CT (64 detectors) and MRI (1.5T).

Equipment Name	Total Number of Clinical Pathways Used	Annual Start-Up Days	Daily Saturated Workload (times)
CT* (64 detectors)	2714	250	120
MR (1.5T)**	4182	250	40

*CT = computed tomography; **MR = magnetic resonance.

The data in Table 3 shows that the number of CT (64 detectors) deployments in the studied hospitals meets the demand of clinical pathways, and the deployment is more appropriate. The number of MR (1.5T) deployments is lower than the theoretical demand, which cannot meet the medical needs of patients in this hospital.

TABLE 3. Comparison of actual equipment deployment quantity and calculation results.

Equipment Name	R	S	Actual Equipment Deployment Quantity	Theoretical Minimum Deployment Quantity	Recommended Deployment Quantity
CT* (64 detectors)	14873	30000	1	0.4958	1.3384
MR (1.5T)**	22918	10000	1	2.2918	2.3146

*CT = computed tomography; **MR = magnetic resonance.

Each hospital can get its own deployment plan recommendation and evaluation by filling in the relevant information. At the same time, the information in the database is becoming more and more complete in the user operation.

Including ALOS, Outpatient Visits, and diagnosis procedure numbers in the medical equipment deployment model has significantly improved the efficiency of resource allocation. ALOS, in the decision-making process for allocating medical equipment, hospitals with longer average lengths of stay may require increased medical equipment resources or optimization of their treatment processes. Our system can effectively reduce hospital stays and improve hospital efficiency through the rational use of medical devices and resource allocation.

Outpatient Visits: Hospitals with high outpatient volumes require more equipment to meet patient needs effectively. This is consistent with other literature, emphasizing the importance of forecasting outpatient visits for better resource planning. When deploying medical equipment, the quantity or type of equipment should be allocated based on the hospital's outpatient visit volume, such as increasing outpatient equipment in high-volume hospitals or updating equipment.

Number of Diagnostic Procedures by Type: Diagnostic procedures directly influence the type and quantity of medical equipment required. By incorporating the demand for specific procedures into the optimization model, we can ensure that resources are allocated according to the varying needs of different procedures. This approach ensures that hospitals are better prepared for both routine and complex procedures. For example, some hospitals may specialize in cardiology or orthopedics, and the equipment needs of these departments may differ significantly from others. The allocation strategy can be adjusted based on the hospital's specific needs.

In conclusion, this study highlights the importance of integrating multiple real-world data factors—ALOS, outpatient visits, and diagnosis procedure numbers—into a decision support system for medical equipment deployment. The model improves resource utilization, helps reduce wastage, and ensures that hospitals are better equipped to handle fluctuating demands.

To validate the practicality and reliability of our system, a satisfaction survey was conducted among doctors and patients at the Shanghai First Maternity and Infant Health Hospital. The survey assessed various aspects including the rationality of equipment layout, user convenience, and User Satisfaction, with each aspect rated on a scale of 1 to 5, where 5 indicates very satisfied and 1 indicates very dissatisfied.

TABLE 4. Survey results.

Interviewee	Rationality of Equipment Layout	User Convenience	User Satisfaction (%)
Physicians	4.6	4.7	95.2
Patients	3.8	3.2	82.1

It can be observed from the table that our system has provided a certain level of assistance in the rational placement of medical equipment.

Physicians, as professionals, tend to rate the rationality and convenience of equipment layout more highly, while patients, as recipients of services, focus more on the convenience and comfort of the medical process. Consequently, there is a certain degree of variation in these ratings, which also suggests that as medical institutions, we need to pay attention to the needs of patients, improve the layout of equipment, enhance patient convenience, and thereby increase overall user satisfaction.

DISCUSSION

The MERDIS system makes it convenient, accurate, and intuitive to get a rational deployment plan and suggestions for medical equipment in the hospital. According to the frequency of clinical pathways on medical equipment and the working ability of the equipment, the theoretical minimum number of medical equipment deployments in different influencing factors can be calculated by the formula, and the recommended deployment quantity of medical equipment can be obtained through the calculation method of big data.

Due to the difficulty of data research, the current data of 52 hospitals is not complete enough, and the deployment of medical equipment is only limited to large medical equipment. In the case of continuous data input and enrichment, the calculation model will become more accurate and expand the scope of medical equipment covered.

When the data tends to be complete and the number of statistical years increases, the function of forecasting the purchased quantity of equipment can be added to the later system version. By the annual average growth rate method, the annual growth rate of equipment deployment can be analyzed, and the annual deployment quantity of the next year or even several years can be estimated according to the equipment deployment base at the end of the previous year.[5] The formula is as follows:

$$R = \sqrt[n]{\frac{y_n}{y_0}} - 1 \quad (7)$$

where y_0 represents the initial number of devices configured in the starting year of recording, y_n denotes the number of devices configured in the most recent year, n is the number of years for which statistics are compiled, and R represents the annual average growth rate of device configuration.

The working capacity of different equipment is also different, and the same kind of equipment is used in different models and working environments. Later research can be closer to the direction of full-cycle management of medical equipment, real-time monitoring of the use of medical equipment, and increase the accuracy of statistics.

CONCLUSION

The MERDIS system represents a groundbreaking advancement in medical equipment management, providing a solid foundation for the future development of macro data management in this sector. Its ability to analyze vast amounts of hospital data, encompassing equipment deployment and clinical practices, offers significant insights and improvements in the field. The system's intuitive interface and analytical capabilities enable healthcare institutions to conveniently and accurately devise rational deployment plans tailored to their specific needs and influenced by various factors. This technology-driven approach promises to streamline the decision-making process for medical equipment resource allocation, leading to more efficient and effective utilization of medical assets.

As the MERDIS system progresses, with ongoing refinements and the accumulation of more data, its predictive models are expected to become increasingly accurate and dependable. This evolution will further empower healthcare decision-makers, enhancing their ability to allocate resources optimally. The success of the MERDIS system is also a credit to the collaborative efforts of participating hospitals, individuals, and various supporting organizations, including the Shanghai Municipal Health Commission's Policy Research Project, the National Natural Science Foundation of China, and the SHDC Clinical Research Plan. Their contributions have been pivotal in realizing this innovative project, which exemplifies the power of integrating technology with practical data to revolutionize hospital resource management.

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