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Design and Application of a New Four-party Collaborative Management Model in the Intelligent Scheduling System for Operating Room

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Abstract: This study targets issues in traditional manual operating room scheduling, including unbalanced resource use, low efficiency, poor inter-departmental communication, and ignored nursing staff personal needs. It developed an integrated surgical scheduling platform to achieve refined, intelligent operating room management while balancing medical quality and humanistic care. Built on the existing Hospital Information System (HIS) with Caché database and Vue + .Net B/S three-tier architecture, the platform integrates five core functions: standardized surgical application, intelligent scheduling, staff rostering, dynamic dispatching, and information collaboration. It combines multi-objective optimization algorithms and Answer Set Programming (ASP) for precise matching of personnel, procedures, time and demands. Comparative analysis was conducted between 66,300 manually scheduled surgeries in 2024 (observation group) and 79,000 surgeries under intelligent scheduling in 2025 (control group). Results showed significant improvements: elective surgery scheduling time reduced by 78.1%, operating room golden time utilization increased by 31.18%, nursing workload balance rose by 27%, nursing emotional exhaustion positive rate decreased by 23%, and nursing turnover reached 0, with enhanced patient experience and staff satisfaction ($p < 0.05$). The platform forms a four-party collaborative management system, realizing efficient resource allocation and providing replicable experience for intelligent operating room management in tertiary hospitals.

Keywords: Intelligent surgical scheduling; Four-party collaboration; Integrated scheduling platform; Data decision-making; Refined management of operating room

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1. Introduction

The operating room is a core diagnosis and treatment unit with high investment and high output in hospitals, and its operational efficiency directly affects the quality of medical services, patient safety and the overall efficiency of hospitals [1–3]. At present, the surgical volume of most large Grade A tertiary hospitals is increasing year by year.

The traditional manual scheduling mode has problems such as uneven human resource allocation, low accuracy of specialist matching, low scheduling efficiency, information asymmetry, and difficulty in taking into account the personalized needs of nursing staff, leading to low utilization efficiency of operating room resources and prominent occupational burnout of nursing staff, which is difficult to adapt to the high-intensity and high-complexity surgical operation needs [4–8].

The Action Plan for Further Improving Nursing Services (2023–2025) issued by the National Health Commission of the People's Republic of China clearly proposes to "promote the informatization construction of nursing and optimize the allocation of nursing resources", which provides a policy basis for the construction of an intelligent scheduling system for operating room [9]. To solve the problems of traditional management and meet the trend of high-quality hospital development and policy requirements, our hospital, as a large Grade A tertiary hospital with more than 3000 beds, launched the construction project of an integrated surgical scheduling platform in 2024, and innovatively constructed a new four-party collaborative management model of "surgical scheduling-human resource allocation-quality supervision-humanistic care". Through technological innovation and process reengineering, we realized the intelligent surgical scheduling, accurate human resource allocation and refined operation management, providing practical reference for the management upgrading of operating room in large Grade A tertiary hospitals.

2. Demand analysis and system design

2.1. System design objectives and demand analysis

2.1.1. Design objectives

Focusing on the pain points of operating room operation and management, the system set four core design objectives:

(1) Improve scheduling efficiency

Replace manual scheduling with automated and intelligent means, reduce tedious operations and human errors, and shorten scheduling time and emergency response time;

(2) Optimize resource allocation

Realize dynamic matching of operating room, nursing staff and surgical needs, and improve the utilization rate of operating room resources and the balance rate of human resource load;

(3) Ensure medical quality

Improve the accuracy of specialist matching, reduce the rate of surgical delay and the incidence of adverse nursing events, and strengthen the whole-process quality supervision of surgeries;

(4) Highlight humanistic care

Take into account the personalized scheduling needs of nursing staff, reduce overtime hours, alleviate occupational burnout, and improve the occupational satisfaction and team stability of nursing staff.

2.1.2. Demand analysis

Combined with the actual clinical operation needs, the system needs to meet four core demands:

(1) Standardization of surgical application

Establish a standardized application process and verification mechanism, reduce invalid surgical preparation, and improve the accuracy of application information;

(2) Intelligence of scheduling algorithm

Integrate multi-dimensional data to build an optimization algorithm, realize the automatic generation of surgical scheduling and staff rostering, and support flexible manual adjustment;

(3) Dynamization of dispatching process

Real-time collection of surgical status information, realize the visualization of surgical process, and improve the response speed of emergency dispatching;

(4) Collaboration of information interaction

Break the information isolated islands of multiple departments, realize the real-time information sharing among doctors, nurses and managers, and reduce communication costs;

(5) Humanization of scheduling management

Support nursing staff's application for desired shifts and shift adjustment, and establish a working load control mechanism to meet personalized needs.

2.2. System development and architecture design

2.2.1. Development tools and technologies

(1) Development tools

Caché database; System mode: B/S structure (Browser/Server); Development architecture: Vue + .Net front-end and back-end separation mode, building a three-tier architecture with separate client-server-database.

(2) System docking

Realize data intercommunication with the hospital's existing information systems such as HIS, Laboratory Information System (LIS) and surgical anesthesia information management system, and complete the extraction, cleaning and fusion of multi-source data through ETL tools;

(3) Terminal support

Compatible with multi-terminal access such as computers, mobile phones, operating room announcement large screens and mobile ward-round PDAs to meet the use needs of different clinical scenarios.

2.2.2. Overall system architecture

The architecture of the intelligent surgical scheduling system is divided into four layers, and each layer collaborates and links to realize the whole-process flow of data and the efficient implementation of functions. The architecture is as follows:

(1) Data source layer

Provides basic data support for system operation, integrates multi-dimensional data such as basic patient information, surgical plans, clinical surgical pathways, surgical risk levels, nursing staff qualifications, specialist capabilities and scheduling wishes, and realizes unified data collection and storage;

(2) Data middle platform layer

As the core data processing unit of the system, it is responsible for data cleaning, verification, fusion and security control, builds a dynamically updated surgical duration prediction database and staff capability database, and provides high-quality data services for upper-layer applications through standardized processing;

(3) System application layer

The core function implementation unit of the system, including five core modules: standardized surgical application, intelligent scheduling, staff rostering, dynamic dispatching and information collaboration. It

integrates surgical management rules and multi-objective optimization algorithms to realize the intelligent operation of various business functions;

(4) Terminal equipment layer

Responsible for the terminal display of system functions and data, supports real-time multi-terminal access and operation, and realizes the multi-channel release and real-time query of surgical scheduling information, staff rostering information and surgical process information.

2.2.3. Design of core function modules

Centering on the new four-party collaborative management model, the system developed five core function modules, which are connected with each other to form a whole-process surgical operation management system of "application-scheduling-dispatching-collaboration-supervision".

(1) Standardized surgical application module

A standardized surgical application process was established, with clear rules such as no application for elective surgeries after 13:00 and no repeated surgical applications on the same day; A real-name reminder and mandatory cancellation mechanism for non-real-name (NA) surgeries was added, with SMS reminders for unreal-named surgeries at 15:30 and automatic cancellation of surgeries with incomplete information at 17:30 to improve the real-name rate of surgeries; Based on the hospital's 3-year surgical historical data, the median reference value was provided for the filling of estimated surgical duration, the surgical adaptability was automatically verified combined with surgical admission criteria, the filling of surgical remark information was standardized, and the invalid surgical preparation and cross-department communication costs were reduced.

(2) Intelligent scheduling module

Integrated 12 types of core data in four dimensions: surgical scheduling, nursing staff qualifications, surgical types, surgical risk levels and humanistic needs, and built a multi-objective optimization algorithm model, taking into account the four objectives of "load balance, specialist matching, optimal efficiency and humanistic care"; Based on Answer Set Programming (ASP) technology, the qualifications, specialist capabilities and personalized needs of nursing staff were converted into logical constraints to realize the automatic generation and optimization of scheduling schemes. The core functions include: ① Automatic main schedule arrangement, arrange main schedule surgeries with one click according to specialist allocation rules, surgical duration prediction data and surgical priority, and automatically generate a waiting queue for non-main schedule surgeries; ② Automatic follow-up schedule arrangement, distinguish follow-up schedule surgeries with color markers, support one-click multiple automatic follow-up schedule arrangements, control the interval between follow-up schedules within 60 minutes, and make full use of the golden time of operating room; ③ Surgical duration prediction, take surgical type, attending surgeon, patient age and other factors as characteristic variables, build a prediction model with random forest algorithm, the prediction accuracy is 40% higher than that of traditional empirical estimation, and realize the preview of surgical process and balanced allocation of resources.

(3) Staff rostering module

It includes two functions: monthly scheduling and daily scheduling, integrating ASP technology and humanized design to realize the accurate and personalized rostering of nursing staff: ① Monthly scheduling, supporting the arrangement of regular shifts, on-call shifts and leave such as parental leave,

home leave and breastfeeding leave, and can automatically generate the next month's staff grouping and shift cycle, solving the problems of difficult sharing of scheduling information and hard to find historical data; ② Daily scheduling, integrating information such as nurses' rotating specialist, capability level, recent shifts and consecutive working hours, automatically arranging suitable nurses first, supporting interface-based fine adjustment, and eliminating missed scheduling; ③ Personalized application, adding the function of applying for shift adjustment and desired shifts, realizing the online submission and approval of nursing staff's scheduling needs, and improving the demand satisfaction rate; ④ Load control, establishing a nurse's consecutive working hours management mechanism, automatically calculating consecutive working hours, and giving red warnings for high-intensity work events exceeding 5 hours to prevent occupational burnout.

(4) Dynamic dispatching module

Realize the whole-process dynamic management of surgeries, and improve the emergency dispatching capacity and quality supervision level: ① Real-time ward round, collect surgical status information in real time through the mobile ward round function, shorten ward round time and reduce the number of ward rounds; ② Process visualization, present the estimated end time and actual process of surgery in the form of Gantt chart, providing accurate data support for emergency operations such as adding, canceling and adjusting surgical schedules; ③ Efficient handover, release handover arrangement information with one click, shorten handover time and improve work efficiency; ④ Risk early warning, the system automatically reminds risk information such as abnormal infection screening and abnormal patient physical signs, and realizes early warning of surgical risks combined with the Clinical Decision Support System (CDSS) to reduce the surgical cancellation rate.

(5) Information collaboration module

Construct an information release system with multi-department linkage including operating room, clinical departments and nursing department, realizing a high degree of consistency of information among doctors, nurses and managers: ① Operating room announcement large screen, displaying surgical staff rostering information, shift color distinction and yesterday's consecutive working hours warning in real time, facilitating the chief nurse's overall dispatching; ② WeChat Work push, medical staff can query surgical arrangements, processes and handover information online at any time, reduce the number of inquiries out of the operating room, and improve work concentration; ③ Nursing management system sharing, nurse shift information and consecutive working hours are transmitted back to the nursing management system with one click, reducing the workload of manual statistics and improving management efficiency. Through multi-channel information collaboration, the cross-department communication time is greatly shortened and the coordination efficiency is improved.

2.3. System implementation guarantee

2.3.1. Organizational guarantee

A "1 + 4 + N" management model was adopted to ensure the implementation of the system: the vice president of the hospital served as the leader to coordinate project planning and resource allocation; Four core groups were set up, including a technical R&D group (Information Department + software engineers), a clinical implementation group (operating room scheduling group), a quality evaluation group (department quality control group) and a humanistic care group (nurse representatives at all levels), responsible for system development, clinical testing,

effect evaluation and personalized demand guarantee respectively; Linkage with N collaborative departments such as Information Data Processing Center, Medical Engineering Department and Medical Affairs Department to form a multi-department linkage mechanism.

2.3.2. System and fund guarantee

Formulated the Implementation Plan of AI Intelligent Scheduling System for Operating Room and Specifications for System Data Security Management, established a system of "weekly review, monthly evaluation and quarterly summary", and timely collected clinical feedback to optimize system functions; The hospital allocated special funds covering the whole process of AI algorithm development, hardware upgrading and staff training to ensure the orderly progress of the project.

2.3.3. Phased implementation

A three-stage implementation strategy of "pilot-promotion-optimization" was adopted:

(1) Pilot stage (January-March), selected 2 specialist operating room in the Department of General Surgery to carry out the pilot, focusing on verifying the adaptability and system stability of surgical scheduling, and collecting clinical feedback to iterate the system version;

(2) Promotion stage (April-June), carried out general training in 3 batches, covering all chief nurses of surgical scheduling, and established a "system communication group" to provide real-time technical support;

(3) Optimization stage (July to present), dynamically adjusted algorithm parameters based on system operation data, incorporated nursing staff's professional title promotion needs and specialist development wishes into scheduling considerations, and continuously improved system functions.

3. Results

3.1. Research data

The integrated surgical scheduling platform was fully and officially put into operation in our hospital in January 2025, and the system operated stably. The data of 66,300 manually scheduled surgeries in the operating room of our hospital from January to December 2024 were selected as the observation group, and the data of 79,000 intelligently scheduled surgeries after the system application in 2025 were selected as the control group. There were no significant differences in baseline data such as the number of operating room (58), the scale of nursing staff and the distribution of surgical departments between the two groups ($p > 0.05$), which were comparable.

3.2. Evaluation indicators

14 evaluation indicators in 4 categories including surgical scheduling efficiency, resource utilization efficiency, nursing human resources and quality, and humanistic care and team stability were selected to comprehensively evaluate the application effect of the system:

(1) Surgical scheduling efficiency indicators

Scheduling time of elective surgeries, emergency response time for adjusting/adding surgical schedules, surgical delay rate, standardized rate of surgical application;

(2) Resource utilization efficiency indicators

Average daily surgical volume per operating room, total surgical volume of operating room, utilization

rate of golden time in operating room, standard deviation of operating room usage time;

(3) Nursing human resources and quality indicators
Balance rate of nursing human resource load, accuracy of specialist matching;

(4) Humanistic care and team stability indicators
Satisfaction rate of nursing staff's desired shifts, average daily overtime hours of nursing staff, positive rate of emotional exhaustion of nursing staff, turnover rate of nursing staff.

3.3. Statistical analysis

SPSS AU software was used for statistical analysis. Measurement data were expressed as ($\overline{x} \pm s$) and tested by *t*-test; Count data were expressed as rate (%) and tested by χ^2 test. $p < 0.05$ was considered statistically significant.

3.4. System application effect

After the application of the integrated surgical scheduling platform, all evaluation indicators were significantly improved compared with before the application, realizing the dual improvement of surgical scheduling efficiency and resource utilization efficiency, and at the same time greatly optimizing the allocation of nursing human resources, enhancing humanistic care and team stability. The differences between the two groups in all indicators were statistically significant ($p < 0.05$). The specific results are shown in **Table 1**.

Table 1. Comparison of various evaluation indicators of operating room operation and management between the two groups

Indicator category	Specific indicator	Before system application (2024)	After system application (2025)	Improvement effect
Surgical scheduling efficiency	Scheduling time of elective surgeries	410 min	90 min	78.1% efficiency improvement
	Emergency response time for adjusting/adding surgical schedules	30 min	10 min	66.7% response speed improvement
	Surgical delay rate	3.50%	0.80%	2.7% reduction
	Standardized rate of surgical application	58%	89%	31% improvement
Resource utilization efficiency	Average daily surgical volume per operating room	4.55 cases/room	4.76 cases/room	0.21 cases/room increase
	Total surgical volume of operating room	66,300 cases	79,000 cases	19.15% growth
	Utilization rate of golden time in operating room	60.86%	92.04%	31.18% improvement
	Standard deviation of operating room usage time	2.81 h	2.13 h	0.68 h reduction
Nursing human resources and quality	Balance rate of nursing human resource load	65%	92%	27% improvement
	Accuracy of specialist matching	85%	98%	13% improvement
Humanistic care and team stability	Satisfaction rate of nursing staff's desired shifts	65%	88%	23% improvement
	Average daily overtime hours of nursing staff	4.2 h	3.5 h	0.7 h reduction
	Positive rate of emotional exhaustion of nursing staff	45%	22%	23% reduction
	Turnover rate of nursing staff	1.38%	0	Zero turnover achieved

After the application of the system, the operation and management of the operating room in our hospital has realized three major transformations: ① Transformation from empirical decision-making to data-driven decision-

making, managers can monitor indicators such as nursing human resource load, surgical efficiency and quality safety in real time, and optimize the allocation of operating room and nursing staff training plans based on data; ② Transformation from decentralized resources to collaborative sharing, breaking the information isolated islands of multiple departments and realizing the intensification, common use and sharing of operating room resources; ③ Transformation from efficiency priority to both efficiency and humanism, while improving operational efficiency, fully meeting the personalized needs of nursing staff and alleviating occupational burnout.

In addition, through the optimal allocation of human resources and efficiency improvement, our hospital has reduced the additional costs such as repeated disinfection of instruments and overtime subsidies caused by surgical delays and personnel mismatches, saving more than one million yuan in annual operating costs; This project won the second prize in the 2025 Annual Excellent Case Collection Activity for Improving Nursing Services of Guangdong Nursing Association, attracted 24 hospitals to conduct research and study, and formed 4 hospital internal standards which were incorporated into the hospital operation management system.

4. Discussion

4.1. System innovation points

The core innovation of the integrated surgical scheduling platform constructed in this study is to create a new four-party collaborative management model of "surgical scheduling-human resource allocation-quality supervision-humanistic care", which breaks through the limitations of the traditional intelligent scheduling system of "emphasizing efficiency, neglecting quality and lacking humanism", and realizes the all-round upgrading of operating room operation and management. The main innovations are reflected in three aspects:

(1) Algorithm and technological innovation

Integrate multi-objective optimization algorithm and machine learning technology, build an algorithm model covering 12 types of core data, break through the limitations of traditional single-objective algorithms, and realize the four objectives of efficiency, quality, fairness and humanism at the same time; Combine ASP technology to convert the personalized needs of nursing staff into algorithm constraints, realize the accurate matching of "person-procedure-time-demand", and improve the scientificity and humanization of scheduling.

(2) Management model innovation

Incorporate quality supervision and humanistic care into the whole-process management of operating room scheduling, build a new four-party collaborative management ecosystem, and break the traditional management barriers of operating room of "emphasizing scheduling, neglecting supervision and ignoring humanism"; Establish a mechanism of "nursing staff participating in scheduling decision-making", realize the transformation of nursing staff from "passively accepting scheduling" to "actively participating in management", and enhance team sense of belonging and cohesion.

(3) Value realization innovation

Realize a win-win situation for patients, nursing staff and hospitals. At the patient level, the surgical delay rate is significantly reduced, the surgical process is more controllable, and the patients' medical experience and surgical safety are greatly improved; At the nursing staff level, the work load is more balanced, personalized needs are met, occupational burnout is alleviated, and team stability is significantly enhanced; At the hospital level, without increasing hardware investment such as operating room, the

surgical undertaking capacity is greatly improved, the operating cost is reduced, and a replicable and promotable refined management model is formed.

4.2. Application experience

(1) High-quality data is the basis for the accurate operation of the system

The intelligent operation of the system relies on multi-dimensional and high-quality basic data. In clinical application, it is necessary to establish a standardized data collection and verification mechanism, standardize the entry of information such as surgical name, surgical duration and staff qualifications to ensure the accuracy and integrity of data; At the same time, establish a dynamic data update mechanism, timely incorporate the latest surgical data and staff information, and improve the prediction accuracy and adaptability of the algorithm model.

(2) Humanistic care is the key to the sustainable operation of the system

Nursing staff in the operating room have high work intensity, and personalized scheduling needs are an important factor to improve their occupational satisfaction. In the design and operation of the system, while pursuing operational efficiency, it is necessary to fully consider the needs of nursing staff for desired shifts, shift adjustment and work load, and balance clinical operation needs and personal wishes through humanized function design to realize the organic unity of efficiency and humanism.

(3) Multi-department linkage is the guarantee for the implementation of the system

The intelligent surgical scheduling system involves multiple departments such as operating room, Information Department, Nursing Department and clinical departments. The construction and operation of the system need to clarify the responsibilities of each department, establish an efficient cross-department communication and data sharing mechanism, break information isolated islands, and ensure the smooth connection of the whole process of surgical application, scheduling, dispatching and execution.

(4) Regular optimization is the core of the system's adaptive development

Medical needs and hospital operation environment are constantly changing. The system needs to establish a regular iteration mechanism of "clinical feedback-data evaluation-function optimization", dynamically adjust algorithm parameters and improve function modules according to the actual clinical operation situation to ensure that the system is always adapted to the needs of the hospital's high-quality development.

4.3. Limitations and prospects

This study has certain limitations: First, the research data are all from a single center of our hospital, the sample has geographical and case type limitations, and the adaptability of the system and algorithm model in other types of hospitals still needs to be further verified; Second, the system is currently mainly aimed at the scheduling optimization of elective surgeries, the scheduling of emergency surgeries still needs partial manual intervention, and the intelligent level of emergency scheduling needs to be improved.

In the future, our hospital will optimize and expand the system from three aspects: ① Improve the emergency surgical scheduling algorithm, combine factors such as the severity of patients' condition, surgical priority and real-time status of operating room resources, build an intelligent emergency scheduling model for emergency surgeries, and improve the resource allocation capacity in emergency situations; ② Realize the whole-process closed-loop management, develop the integrated function of scheduling and appointment, deeply link the

system with the patient's pre-operative examination appointment system, realize the whole-process closed-loop management of patients' pre-operative examination, surgical appointment, scheduling and execution, and further improve the patients' medical experience; ③ Expand the application scope of the system, promote the scheduling logic and management concept of this system to other hospital operation links such as outpatient appointment and bed dispatching, and realize the optimal allocation of the whole hospital's resources; At the same time, refine the classification of nurses' specialist proficiency, improve the function of specialist capability map, and realize a more accurate matching between nursing staff and surgical types.

In addition, we will carry out multi-center research in conjunction with other hospitals of different grades and types to verify the universality and adaptability of the system, further optimize the algorithm model, and provide more universal practical experience for the refined and intelligent management of operating room in hospitals at all levels across the country.

5. Conclusion

Through technological innovation and process reengineering, the integrated surgical scheduling platform integrates surgical management concepts and multi-objective optimization algorithms, and constructs a new four-party collaborative management model of "surgical scheduling-human resource allocation-quality supervision-humanistic care", which effectively solves the pain points of unbalanced resource utilization, low scheduling efficiency, prominent communication barriers and insufficient humanistic care under the traditional manual scheduling mode. After the application of the system, the scheduling efficiency and resource utilization efficiency of the operating room are significantly improved, the accurate allocation of nursing human resources is realized, the medical quality supervision is strengthened, and at the same time, humanistic care is highlighted, the occupational satisfaction and team stability of nursing staff are improved, and the transformation of operating room operation management from experience-driven to data-driven is realized. The platform provides a feasible path and practical experience for the refined and intelligent management of operating room in large Grade A tertiary hospitals, and has important promotion and application value.

Disclosure statement

The authors declare no conflict of interest.

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