

MULTI-OBJECTIVE OPTIMIZATION OF OPERATING ROOM RESOURCE SCHEDULING IN COUNTY-LEVEL HOSPITALS

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Abstract: Aiming at the prominent problems of experience-driven manual scheduling in county-level hospitals such as unbalanced resource allocation and delayed emergency-surgery response, this paper innovatively establishes a multi-source dataset integrating field investigation, medical staff questionnaires and simulation case library. Considering practical hard constraints including surgery urgency, surgeons' expertise, special-equipment requirements and medical staff working-hour limits, a multi-objective integer-programming scheduling model is built based on operations-research sequencing-allocation theory. Different from existing studies mainly targeting tertiary hospitals, the proposed model is designed for lightweight deployment at grassroots hospitals, realizing four-dimensional matching scheduling and rapid rescheduling for unexpected events without large-scale information-system reconstruction. Validated with data from Qianwei County People's Hospital, the model increases average operating-room utilization from 68.3% to 81.7%, shortens patients' average waiting time from 5.2 days to 4.1 days, reduces surgery delay rate from 18.9% to 9.8%, and keeps emergency-surgery response delay within 30 min. Rescheduling can be completed within 3 min under emergency insertion disturbance. It provides a practical technical solution for intelligent and refined operating-room scheduling of county-level hospitals.

Keywords: Operating-room resource scheduling; Multi-objective optimization; Operations research; County-level hospital; Scheduling simulation

1 INTRODUCTION

As core bottleneck resources of county-level general hospitals, operating-room scheduling directly governs the overall operational efficiency of medical institutions, patient satisfaction, and the rational utilization of medical human-resources and equipment resources [1]. A large number of county-level hospitals across China still adopt empirical manual scheduling modes for surgical arrangements. Subject to insufficient information construction, limited staffing and complicated mixed demands of elective and emergency surgeries, these hospitals are confronted with prominent practical problems, including low operating-room utilization, excessively long waiting cycles for elective patients, and frequent schedule disruption caused by temporary insertion of emergency operations [2-3]. Therefore, exploring optimized scheduling solutions matching the actual operational conditions of county-level hospitals has important practical value for improving grassroots medical service capacity and alleviating the contradiction between supply and demand of county-level medical resources.

A great number of existing domestic and foreign studies have investigated operating-room resource scheduling by adopting operations-research theories, integer programming and various intelligent heuristic algorithms [4-5]. Nevertheless, most existing research objects are large-scale tertiary hospitals with complete information systems and abundant human-resource reserves [6]. Few studies focus on county-level grassroots hospitals with tight resource budgets and imperfect data infrastructure [7]. Most existing models require complete hospital information system interfaces and massive historical high-quality operation data as support, lacking targeted constraint settings for surgeon working-hour limits, special equipment matching and emergency-surgery disturbance scenarios in grassroots hospitals. Moreover, empirical validations based on real-world survey data from county-level hospitals are relatively insufficient [8]. There still exists an obvious research gap between theoretical scheduling models and lightweight deployable schemes for county-level medical institutions.

To bridge the above research gap, this paper selects Qianwei County People's Hospital, a typical county-level comprehensive hospital, as the empirical research object. On the basis of field investigation and structured questionnaires for front-line medical staff, this paper further constructs a simulation case library to supplement scarce real-world samples, and builds a multi-objective integer-programming scheduling model under comprehensive constraints of surgical urgency, surgeons' professional expertise, special-equipment availability and medical-staff working-hour limits. The model takes operating-room utilization rate, average patient waiting time and surgical delay rate as optimization objectives, and supports rapid rescheduling when emergency surgeries are inserted unexpectedly. The marginal contributions of this study are as follows. Firstly, a multi-source data combination mode integrating field survey, questionnaire feedback and simulation cases is proposed for grassroots hospitals with insufficient data accumulation. Secondly, a lightweight optimization model without large-scale information-system reconstruction is constructed, which can provide operable decision-making reference for similar county-level hospitals to realize refined operating-room resource management.

2 METHODOLOGY

This study focuses on the optimization of operating-room resource scheduling in county-level hospitals. Research is systematically carried out from three core dimensions: definition of research objects, data collection, and modeling method design. A complete logical chain of “problem identification-data support-model solving-effect verification” is constructed, so as to provide references for intelligent resource scheduling of operating rooms in grassroots medical institutions.

2.1 Research Object

This study selects the operating rooms of Qianwei County People’s Hospital as a typical research sample, focusing on the intelligent scheduling and optimal allocation of operating-room resources in county-level general hospitals. As a county-level comprehensive medical institution undertaking dual tasks of emergency and critical-illness treatment as well as routine medical services in the region, its operating-room scheduling status exhibits typical characteristics of grassroots medical institutions, which qualifies it as an effective empirical carrier for this optimization research.

The hospital performs approximately 3,800 operations per year, including elective and emergency surgeries. The number of key medical equipment such as high-frequency electrotomes, anesthesia machines and shadowless lamps in operating rooms is limited. Some surgeries require matching special equipment, forming explicit constraint conditions for equipment utilization. Taking the hospital’s surgical scheduling scenarios as the basis, model verification is conducted under complex scenarios including batch scheduling of routine surgeries and temporary insertion of emergency surgeries to comprehensively test the model’s applicability.

2.2 Data Collection

To ensure the scientific nature of the scheduling-model construction, the accuracy of data-driven computations and the reliability of the research results, this research uses a multi-source data fusion collecting system integrating field investigation, questionnaire survey and simulation case design. The procedures and processing rules for obtaining and handling different kinds of data are as follows:

Field investigation data collection: The research group carried out field investigations at the People’s Hospital of Qianwei County in August 2025. A primary dataset was established by utilizing the publicly accessible diagnosis-treatment information, clinical guidelines, news reports and surgical-scheduling data of other county-level hospitals from academic journals. By referring to the past six months’ surgical business data and sorting them, 112 valid surgical records were ultimately selected after the data had been processed by removing the missing values, abnormal values and duplicate records and verifying their rationality based on medical knowledge and business logic in an Excel file.

Collection and analysis of questionnaire-survey data: To investigate the subjective feelings and actual difficulties in operating-room resource allocation, questionnaires were specially prepared for medical staff from different departments in the hospital. After screening, 28 valid questionnaires were finally obtained. The questionnaire consists of three main aspects: firstly, the cognition of the scheduling objects, which involves the preference of medical staff for certain scheduling bases like surgery urgency and appointment time; secondly, the evaluation of the scheduling problems, evaluating the deficiencies of the present scheduling system from the viewpoints of scheduling-information accuracy, response speed and departmental cooperation efficiency; thirdly, the priority-ranking requirements, indicating the importance of factors such as patient safety, surgical efficiency and full use of resources. After performing reliability and validity tests, the questionnaire data is utilized to determine the weights of the objective function in the model and to verify the optimal direction of the scheduling strategies.

Simulation-case library establishment and data supplementation: In order to make up for the lack of field investigation data in extreme situations and complicated combined conditions, a standardized surgical simulation-case library is built according to the real-world business characteristics of Qianwei County People’s Hospital. The library consists of 120 simulated surgical cases which include various types of surgeries, urgencies and resource requirements. The case library is established by using MATLAB random-generation algorithms which strictly follow the hospital-resource constraints such as the number of operation rooms, working hours of the staff and special equipment regulations to generate standardized case-input matrices for model training, parameter adjustment and test of generalization ability. This method can effectively increase the number of data samples and ensure sufficient model verification in different scenarios.

2.3 Research Methods

Guided by the sequencing and allocation theory of operations research, this study combines multi-objective optimization thinking, MATLAB numerical simulation techniques and controlled comparison methods to develop and validate an intelligent scheduling model for operating room resource arrangement. The detailed research methodology is elaborated as follows. This research takes operations research theory as the core technical support and adopts scientific priority sorting rules for scheduling optimization. Multiple key influencing factors, such as surgical emergency level, predicted operation duration and patient waiting time, are comprehensively considered to formulate dynamic priority assignment strategies for various surgical tasks. Specifically, emergency surgeries are set as the highest-level tasks,

while different priority weights are allocated to elective surgeries according to their waiting cycle and operational complexity, forming a scientifically ordered surgical execution queue. On this basis, the integer programming algorithm is utilized to reasonably distribute sorted surgical tasks to matched operating rooms and available time windows, and establish standardized linear constraint equations. The model strictly complies with practical hard operational limits, including the effective working duration of medical staff, exclusive occupation rules of surgical equipment, and non-overlapping operation restrictions for individual surgeons. Through the above optimization logic, accurate four-dimensional matching covering surgeries, operating rooms, time slots and equipment resources is achieved. Meanwhile, a complete multi-objective optimization function is constructed to satisfy the comprehensive scheduling demands of actual hospital scenarios, with core optimization objectives formulated as follows.

Maximize comprehensive operating-room utilization rate (actual surgical duration / total available duration); Minimize the average patient waiting time; Minimize the surgical delay rate. Multi-objective collaborative optimization is realized via the weighted-sum method.

All modeling procedures, numerical solutions and simulation experiments of the operating room scheduling optimization model are implemented on the MATLAB R2021a platform. In the data preprocessing stage, uniform normalization processing is performed on continuous evaluation indicators including surgical duration and patient waiting time. For discrete categorical factors such as surgical urgency levels and medical equipment types, quantitative encoding and priority assignment strategies are adopted to realize standardized numerical conversion. Meanwhile, practical operational limitations, including staff working time constraints and equipment occupation rules, are mathematically transformed into constraint matrices, forming standardized and structured model input datasets. In the modeling and solution stage, a multi-objective optimization framework is constructed, which takes actual surgical task lists, operating room resource pools, medical staff shift arrangements and equipment available time windows as core input variables. During simulation verification and result analysis, both field investigation data and standard simulation case data are imported into the model for comparative experiments. To eliminate the interference of random simulation errors, each experimental group is repeated ten times, and the average value is taken as the final valid result. The model automatically outputs optimized surgical scheduling schemes and key evaluation metrics, including operating room resource utilization and average patient waiting time. Furthermore, the built-in drawing module of MATLAB is utilized to generate scheduling Gantt charts, which visually reflect the surgical execution timeline and dynamic occupancy status of operating room resources, providing intuitive graphical support for result verification and scheduling mechanism analysis.

The methodological framework proposed in this study integrates theoretical modeling accuracy and practical engineering applicability. Developed fully based on the actual operational data and basic management conditions of county-level hospitals, the presented scheduling model does not require extra information system investment or hardware upgrading. It can effectively ensure the rationality and credibility of the research outcomes, and provide a feasible, replicable and generalized optimization scheme for operating room resource scheduling in peer county-level medical institutions.

3 RESULTS

3.1 Presentation of Research Results

Targeting the actual operating room scheduling dilemma of Qianwei County People's Hospital, this study conducts targeted modeling and numerical solution, and the proposed scheduling method achieves prominent optimization performance in practical scenario verification. The research core findings are quantitatively verified through one typical scenario simulation test and two groups of key comparative tables. Among them, Table 1 systematically compares the differences in core performance indicators between the hospital's traditional manual scheduling mode and the intelligent scheduling scheme generated by the proposed model.

Table 1 Comparison of Core Indicators between Manual Scheduling and Model-Based Scheduling

Evaluation Indicators	Manual Scheduling (Control Group)	Model-based Scheduling (Research Group)	Improvement
Average operating-room utilization rate	68.3%	81.7%	+13.4 percentage points
Average patient waiting time	5.2 days	4.1 days	-21.2%
Surgical delay rate	18.9%	9.8%	-9.1 percentage points
Emergency-surgery response delay	≥ 2 hours	< 30 minutes	Significant improvement

As summarized in Table 1, the MATLAB-based optimization scheduling framework outperforms conventional manual empirical scheduling in all major operational metrics. The proposed model substantially improves the average utilization efficiency of operating room resources, enabling the hospital to fully tap the inherent service potential of existing operating rooms without extra hardware renovation or equipment investment. In addition, the optimized scheduling strategy effectively reduces patients' average waiting time and optimizes the overall medical service experience. The surgical delay rate induced by resource conflicts and unreasonable task arrangement is also reduced by nearly 50%. In particular, when unexpected emergency surgical tasks are inserted, the model restricts the overall

response delay within 30 minutes. In contrast, traditional manual scheduling usually requires more than two hours for temporary adjustment, which demonstrates the superior dynamic adaptability and emergency response capability of the proposed method. Further, Table 2 conducts a comprehensive multi-objective optimization analysis to explore model scheduling performance under diverse weight combination configurations.

Table 2 Multi-Objective Optimization Analysis of Model-Based Scheduling under Different Weight Combinations

Scheme	Utilization weight (α)	Waiting-time weight (β)	Operating-room utilization rate	Average patient waiting time	Scheme characteristics
Scheme A	0.8	0.2	83.5%	4.6 days	Efficiency-prioritized
Scheme B	0.6	0.4	81.7%	4.1 days	Comprehensive balance
Scheme C	0.4	0.6	79.1%	3.8 days	Fairness-prioritized

Table 2 illustrates model outputs by adjusting weight coefficients for utilization rate and waiting time within the objective function. Scheme A achieves the highest operating-room utilization rate of 83.5%, yet patient waiting time is only reduced by 12% with limited overall improvement. Scheme C yields the shortest patient waiting time of 3.8 days at the cost of a decreased utilization rate of 79.1%. Taking both hospital operational efficiency and patient-service experience into consideration, Scheme B realizes the optimal balance: maintaining a high utilization rate of 81.7% while shortening waiting time by 21.2%. Therefore, the weight combination of Scheme B is determined as the core scheduling strategy of this study.

3.2 Test on Emergency-Response Capacity

To investigate the stability of the model under real disturbances, an experiment named "emergency appendectomy" is conducted. In the execution of the original plan, an "emergency appendectomy" (lasting approximately 60 minutes) is simulated to be done immediately. When a new task arises, the model needs 3 minutes to complete the rearrangement calculation. The elective operation which was arranged at another time will be put off for 50 minutes. The other operations are unaffected and there is no conflict among the equipments or personnel. From these results, it can be concluded that the model can quickly adapt to emergencies and deal with disturbances efficiently. The emergency-scheduling speed of the model is much faster than the conventional manual adjustment (usually taking 20-30 minutes), thus significantly improving the capability of operating-room scheduling in unexpected situations.

4 CONCLUSIONS

This paper develops a multi-objective integer-programming scheduling model for county-level hospital operating rooms based on operation-research theory, taking Qianwei County People's Hospital as the empirical study object. By using a multi-source data set which combines field investigation, medical-staff questionnaires and simulation case library, the model takes into account the practical constraints such as surgery urgency, surgeons' experience, special-equipment requirements and staff working-hour limits in an integrated way. The simulation results indicate that the presented simple model can greatly improve the operating-room utilization, shorten the patients' waiting time and decrease the surgical delay rate. Furthermore, it can quickly rearrange the surgery schedule when emergencies occur. Without major reconstruction of the hospital information systems, the model can be directly applied to the daily surgical arrangements in county-level general hospitals, providing quantitative decision support for the refined management of operating-rooms and showing good practical feasibility for primary medical institutions.

However, this study also has some limitations. The simulation uses deterministic surgical parameters without taking into account all the practical random disturbances, and the model verification is only based on one county level hospital case. For the research in the future, stochastic optimization methods will be applied to deal with the real world random uncertainties. Multi-hospital real-world data will be utilized to adjust the model, and it can be extended to provide support for the joint resource scheduling of different categories in primary health care situations.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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