Application of AI-Based Surgical Scheduling in Orthopedic Surgery Centers

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BACKGROUND

- Lean management in surgical centers is key to high-quality operations for healthcare institutions. Given the high proportion of the surgical department in hospital budgets, it is particularly important to effectively plan elective, emergency and ambulatory surgeries, optimize the available human and material resources, and maintain a high level of medical care at all times. This not only shortens patient waiting time but also improves the operational efficiency of the surgical department and even the entire hospital[1].
- The traditional scheduling mode of surgical centers relies on manual planning by head nurses, which has problems such as low efficiency, uneven resource allocation and insufficient operating room utilization, making it difficult to meet the refined operation needs of surgical centers. Therefore, it is urgent to optimize the scheduling process through information technology means. Effective utilization of operating room resources by optimizing surgical scheduling can alleviate this problem, but it requires accurate prediction of surgical duration, and the current standard methods for predicting surgical duration have errors. The use of artificial intelligence technology is expected to improve the accuracy of surgical duration prediction [2].
- This study aims to explore whether there is evidence that artificial intelligence (AI) is superior to the current industry standards in predicting surgical duration, and to conduct a secondary analysis to determine whether the implementation of the adopted model can bring efficiency improvement.

METHOD

This study constructed an AI-based scheduling optimization scheme for surgical centers, which consists of three core modules. The specific implementation methods are as follows:

1. AI-DRIVEN ACCURATE PREDICTION OF SURGICAL DURATION

Historical surgical data were collected to train the AI model, and a deep graph learning algorithm was adopted to improve prediction accuracy and reduce the interference of surgical duration fluctuations on scheduling. To verify the model's effectiveness, orthopedic surgery-related data were selected in this study to compare and verify the deep graph learning method with the industry-common Mean-10 method and Mean-all method. Meanwhile, referring to the relevant research results of Memorial Sloan Kettering Cancer Center (MSK) [3], a performance comparison was conducted with the traditional deep neural network (DNN) model. Among them, the Mean-10 method [2] completes the prediction based on the average duration of the surgeon's last 10 identical surgeries; the Mean-all method, as an industry standard [4], adopts the average duration of the surgeon's historical identical surgeries for prediction.

2. AI-DRIVEN APPLICATION OF AUTOMATIC SCHEDULING

Based on the Non-dominated Sorting Genetic Algorithm II (NSGA II), an operating room scheduling optimization model was constructed and exclusive software was developed to realize the automatic generation of the optimal scheduling plan for the surgical center on the next day, assisting head nurses in completing scheduling work and reducing the load of manual operations. The details are as follows:

METHOD

2.1 Input and Predicted Duration

Let $i = 1, \ldots, m$ represent the surgeries to be scheduled on the next day, and $r = 1, \ldots, n$ represent the operating rooms open on the day. The definition of parameters and variables is as follows:

$x_{ir} \in \{0,1\}$: If surgery i is assigned to OR r then x_{ir} =1, otherwise 0;

$\hat{t}_i$: AI-predicted duration of surgery i (hours);

t_r: Predicted total workload of operating room r (hours);

D : Standard opening duration of a single operating room (hours), taken as 9 hours in this study.

The workload of an operating room tr is given by the assignment relationship:

$$t_r = \sum_{i=1}^{m} \hat{t}_i \, x_{ir}, \ \forall r = 1, \ldots, n.$$

2.2 Objective Function

On the premise of strictly satisfying business rules (hard constraints), multi-objective optimization (weighted or hierarchical) is adopted for scheduling to maximize the average utilization rate of operating rooms and improve load balancing.

2.3 Constraint Conditions

- **Unique Assignment** - $\sum_{r=1}^{n} x_{ir} = 1, \ \forall i = 1, \ldots, m.$
- **Fixed Room** - For the designated surgery i fixed to $r(i)$: $x_{i,r(i)} = 1$

2.4 Solution and Output

Based on NSGA II, an operating room scheduling optimization model was constructed to complete the solution in seconds and output a scheduling table directly applicable to the execution of scheduling on the next day (including operating room, sequence and estimated time).

3. CONSTRUCTION OF MULTI-DIMENSIONAL EVALUATION SYSTEM

Abandoning the single-index evaluation model, two core evaluation indicators—the average utilization rate of operating rooms and the load balancing of operating rooms—were established to realize a comprehensive quantitative evaluation of the scheduling optimization effect.

To further verify the effectiveness of the scheme, a 7-day controlled study was designed, with two groups: the manual scheduling group, the AI automatic scheduling group (and the actual operation result group). The differences between the two groups in core evaluation indicators were compared and analyzed to verify the practical value of AI technology in the operation of surgical centers.

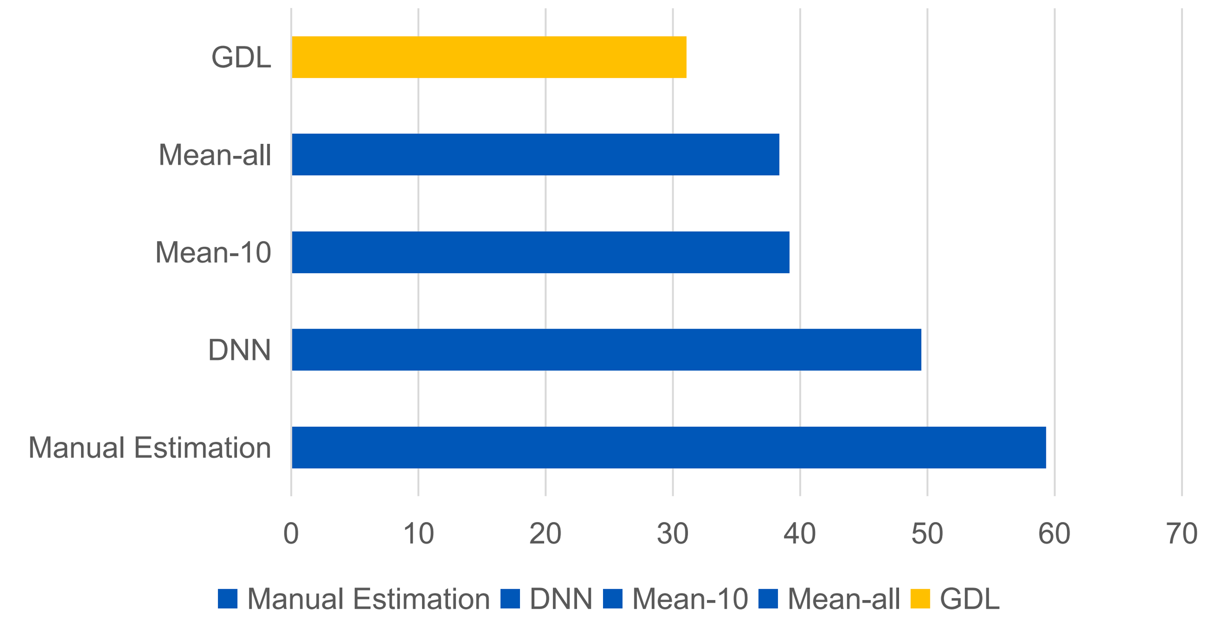
RESULTS

1. GDL MODEL LEADS IN ORTHOPEDIC SURGERY DURATION PREDICTION ACCURACY.

Preliminary test results showed that multiple sets of comparative verification all proved the excellent performance of the AI surgical duration prediction model constructed in this study.

In the orthopedic surgery data test, the prediction error of the GDL (Graph Deep Learning) method was 31.06 minutes, which was significantly better than the Mean-10 method (39.16 minutes) and the Mean-all method (38.34 minutes). Compared with the traditional DNN model (average error 49.5 minutes) and manual estimation (average error 59.3 minutes), the prediction error of this model could be further controlled within 20 minutes, showing an obvious advantage in comprehensive prediction accuracy.

FIGURE 1 Comparison of Prediction Errors (mins)



2. AI AUTOMATED SCHEDULING CUTS HEAD NURSES' SCHEDULING TIME DRASTICALLY

The AI automatic scheduling application achieved remarkable results, shortening the head nurse's manual scheduling time from 3 hours to 0.5 hours, reducing the manual operation time by 83%, and greatly improving the scheduling efficiency.

3. CONTROLLED STUDY ENABLES QUANTITATIVE VERIFICATION OF AI'S OPERATIONAL EFFICACY IN OPERATING ROOMS

The subsequent 7-day controlled study will further clarify the differences in the core indicators of the average utilization rate and load balancing of operating rooms, providing data support for verifying the effect of AI technology in improving operating room utilization and balancing loads.

Definitions of indicators:

Average Utilization (AU)

$$AU = \frac{\sum_{r=1}^{n} t_r}{\mathrm{D} * n}$$

where tr is the total surgical duration of the r-th open operating room (hours), D is the standard opening duration of a single operating room (hours), and n is the number of open operating rooms.

Load Balance (LB)

$$LB = \frac{1}{n}\sum_{r=1}^{n} (t_r - \bar{t})^2$$

where tr is the total surgical duration of the r-th operating room, t¯ is the average value of the total surgical duration of each operating room, and n is the number of open operating rooms.

Indicator Dimension	AI Scheduling	Manual Scheduling	Difference	Impact
Average Utilization Rate	98.92%	102.26%	-3.34%	Under the same conditions and with the same surgical volume, the time required after AI optimization is shorter
Load Balancing	346.6 mins	576.0 mins	-229.4 mins	AI ensures the average workload and balanced load of each operating room

TABLE 1: Comparison of AI Scheduling and Manual Scheduling

Note: This project is currently in the research trial phase. The relevant data collection is solely for research and academic exchange purposes, and the findings have not yet been applied in clinical or practical settings.

CONCLUSIONS

- The research results show that in the same surgical scheduling task, AI scheduling can realize accurate permutation and combination calculation and efficient scheduling logic. Compared with manual scheduling, under the premise of completing the same surgical volume, the total time of a single operating room is shorter and the overall operational efficiency is higher, while achieving load balancing among all operating rooms. The AI-based scheduling optimization scheme for surgical centers can effectively solve the problems of low efficiency and insufficient accuracy of the traditional manual scheduling mode, significantly shorten the scheduling time, and improve the scientific and rationality of the scheduling plan.
- Preliminary research results show that the AI-driven surgical duration prediction model has higher accuracy, providing a reliable data basis for optimizing scheduling; the automatic scheduling tool can greatly reduce the scheduling time of managers and improve accuracy. If the subsequent controlled study can further verify its effectiveness in improving operating room utilization and balancing loads, it will provide an important reference for surgical centers to clarify the optimal operation direction, and also respond to the advocacy of information technology empowering medical process optimization in the AORN Perioperative Practice Guidelines. This study has limitations: it is currently at the theoretical research level, and the research results have not been put into clinical and practical application scenarios, so their effectiveness and practicability need to be further verified in real environments. Nevertheless, the AI-based scheduling optimization scheme for surgical centers shows great potential and advantages.

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REFERENCES

[1] Bottani E. Internet of Things and New Technologies for Tracking Perioperative Patients With an Innovative Model for Operating Room Scheduling: Protocol for a Development and Feasibility Study[J].

[2] Spence C, Shah O A, Cebula A, et al. Machine learning models to predict surgical case duration compared to current industry standards: scoping review[J].

[3] Strömblad C T, Baxter-King R G, Meisami A, et al. Effect of a Predictive Model on Planned Surgical Duration Accuracy, Patient Wait Time, and Use of Presurgical Resources: A Randomized Clinical Trial[J].

[4] Master N, Zhou Z, Miller D, et al. Improving predictions of pediatric surgical durations with supervised learning[J]. International Journal of Data Science and Analytics, 2017, 4(1):35-52.