Optimizing Hospital Resource Allocation

Using Linear Programming and Queueing Simulation
Case Study of Tokyo Dermatology Clinic

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Executive Summary

"Y" Dermatology Clinic in Tokyo, Japan faces significant challenges in its operations, with patient waiting times regularly exceeding 1 hour. "Group 4" members analyzed the operations and applied optimization and other modeling techniques to determine optimal staffing levels and analyze cost trade-offs between staffing and waiting times.

Methodology

Multi-method decision analytics framework combining:

- Linear Programming for cost-optimal staffing
- Discrete-Event Simulation for stochastic modeling
- Hybrid workflow design for process improvement

Key Findings

- Optimal weekday configuration: <u>3 doctors</u> (30-minute average wait, 79% utilization)
- Optimal Saturday configuration: <u>2 doctors</u> (cost-effective for shorter sessions)
- Hybrid reservation workflow <u>reduces wait times by 20-30%</u> without additional staffing
- Process optimization delivers same performance gains as adding one physician

Problem Statement

Clinic Profile

- Location: Near “X” Station, Tokyo
- Service Area: 15,000-20,000 residents
- Services: General & Pediatric Dermatology
- Current Staff: 2 weekday doctors, 3 Saturday
- Consultation Time: 5-15 minutes

Current Operational Challenges

- Patient waiting times frequently exceed 1 hour
- Uneven patient arrival patterns throughout the day
- No reservation system - purely walk-in based
- Sequential patient processing causing bottlenecks
- Staff fatigue and reduced patient satisfaction

⚠ Impact

- Reduced patient satisfaction
- Potential revenue loss
- Staff burnout and fatigue
- Inefficient resource utilization
- Overcrowding during peak hours

Research Objectives

Primary Research Questions

1. Optimal Staffing
How many doctors are required on weekdays and Saturdays to achieve an acceptable balance between service quality and operational efficiency?

2. Cost Trade-offs
What cost trade-offs emerge between adding staff versus tolerating longer waiting times?

3. Workflow Redesign Impact
How can workflow redesign, through a hybrid reservation and parallel nurse-prep model, improve throughput without additional staff?

Success Metrics

≤30
Minutes Average Wait

75-85%
Target Utilization

Minimize
Total Operating Cost

Foundational Research

Primary Research Questions

Cayirli and Veral (2003)
Outpatient Scheduling Models

- Foundational review of outpatient scheduling systems
- Tension between patient waiting times and provider idle time
- Hybrid appointment-walk-in models balance utilization with satisfaction

Green (2006)
Queueing Theory in Healthcare

- Stochastic variability in arrivals and service times
- Non-linear magnification of waiting times
- Key consideration for high-traffic outpatient environments

Modern Applications

Harper and Shahani (2002)
Linear programming and simulation for hospital capacity management

Zhou et al. (2020)
Discrete-event simulation for Chinese dermatology department redesign

We based our research on the above to address the research problem.

Methodology Overview

Linear Programming
- Baseline capacity optimization
- Deterministic model for steady-state analysis
- Parameter calibration for simulation

Queueing Simulation
- Stochastic performance analysis (SimPy)
- Random arrivals and service times
- 50-100 replications per scenario

Cost & Sensitivity
- Managerial trade-off analysis
- Staff cost vs. waiting cost optimization
- Sensitivity analysis across parameters

Workflow Redesign
- Hybrid reservation system evaluation
- Process improvement scenarios
- Parallel nurse-assisted preparation

The methodology combines deterministic optimization with stochastic simulation to provide both theoretical optimums and realistic performance estimates under uncertainty.

Data and Parameters

Patient Arrival Patterns

Time Slot	Weekday Patients	Saturday Patients	Peak Periods
09:00-10:00	10	15	Morning Rush
10:00-11:00	15	23	Peak Morning
11:00-12:00	19	25	Peak Morning
14:00-15:00	13	-	Afternoon Start
16:00-17:00	23	-	Peak Afternoon
17:00-18:00	25	-	Peak Evening

Service Time Parameters

Simple Cases

8

Minutes (Mean)

Standard deviation: 2 minutes

Medium Cases

15

Minutes (Mean)

Standard deviation: 3 minutes

Complex Cases

25

Minutes (Mean)

Standard deviation: 5 minutes

Linear Programming Model

Decision Variables

- x_t: number of patients served during hour t
- q_t: number of patients waiting at the end of hour t

Parameters:

- A_t: expected arrivals during hour t
- C_d: service capacity per doctor per hour
- D: number of doctors available

Objective Function:

Minimize: Σq_t (total queue length over the day)

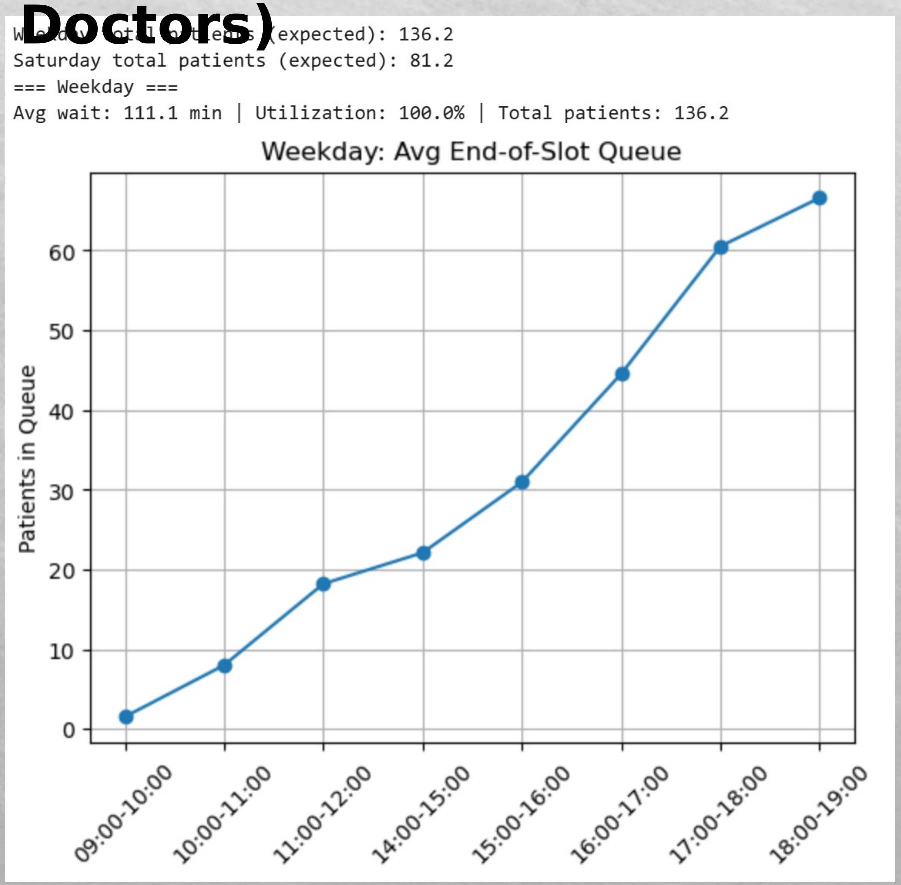
Constraints:

- $x_t \leq D \times C_d$ (Doctor capacity limit)
- $q_t = q_{t-1} + A_t - x_t$ (Flow conservation)
- $q_t \geq 0, x_t \geq 0$ (Non-negativity)

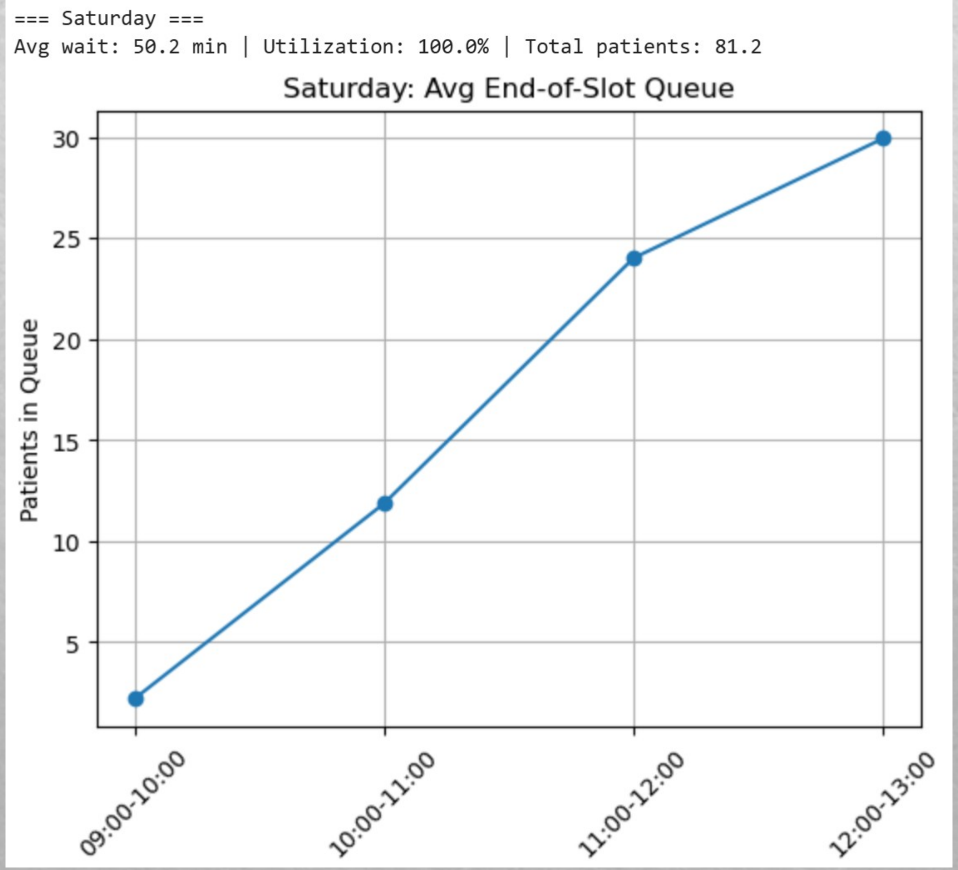
Model provides approximate steady-state view of clinic congestion and serves as foundation for parameter calibration in subsequent simulation.

Linear Programming Model - Result

Weekday Results (2 Doctors)



Saturday Results (3 Doctors)



Even though total daily capacity appears sufficient in aggregate, hourly imbalances cause pronounced congestion during late morning & late-afternoon peaks, confirming need for stochastic simulation to capture real-world variability

Simulation Model Design

Discrete-Event Simulation (SimPy)

Arrival Process

- Poisson arrivals with hourly variability
- Patient segmentation by age and complexity
- Proportional distribution within time slots
- Random arrival times within each hour

Service Process

- Normal distribution for service times
- Means and std devs by case complexity
- Minimum service time: 2 minutes
- First-come-first-served queue discipline

Resource Modeling

2-5
Doctors

3
Examination Rooms

5
Total Support Staff

Performance Metrics

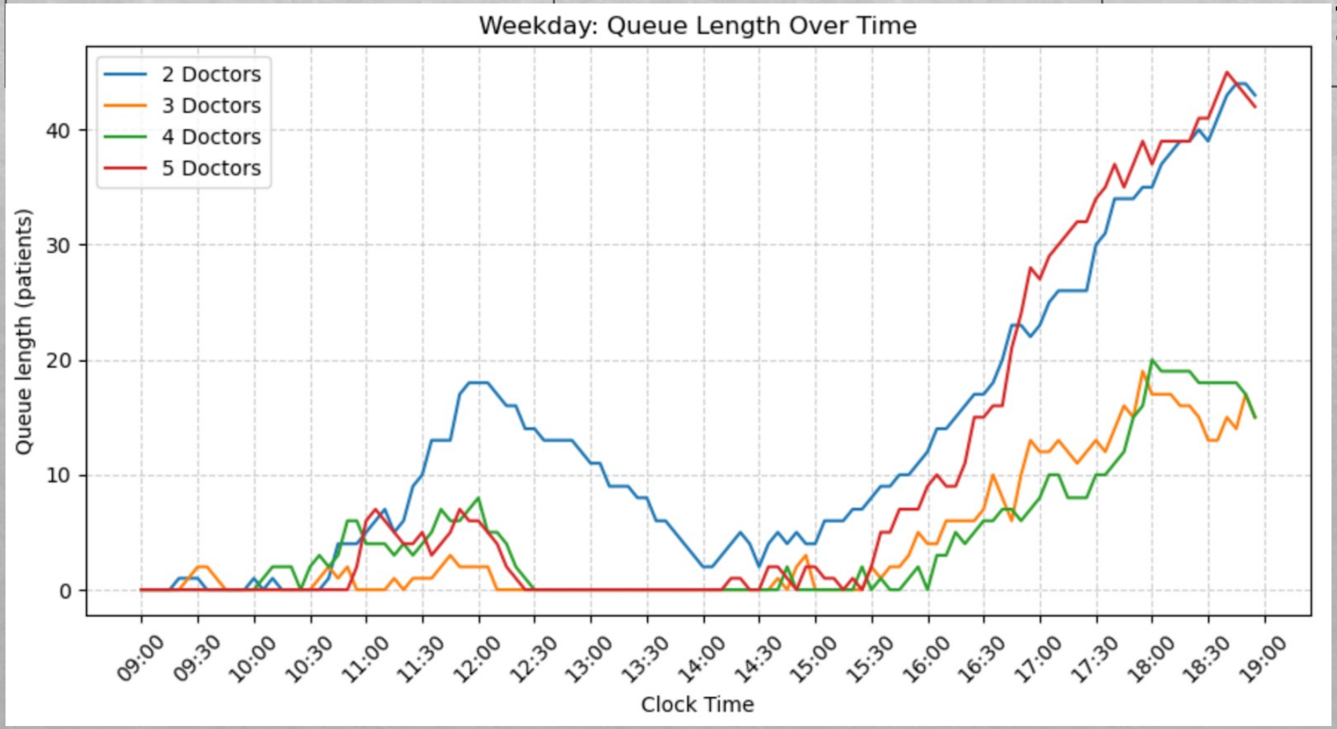
Average Waiting Time

Doctor Utilization

Queue Length Over Time

Simulation Results - Weekday

Doctors	Average Wait (min)	Utilization (%)	Assessment
2	66.4	93.1%	✖ Overloaded System
3	**30.9**	**79.3%**	✅ **Optimal Balance**
4	30.7	79.6%	⚠ Diminishing Returns
[illegible]	[illegible]	1.0%	⚠ Increased Variability

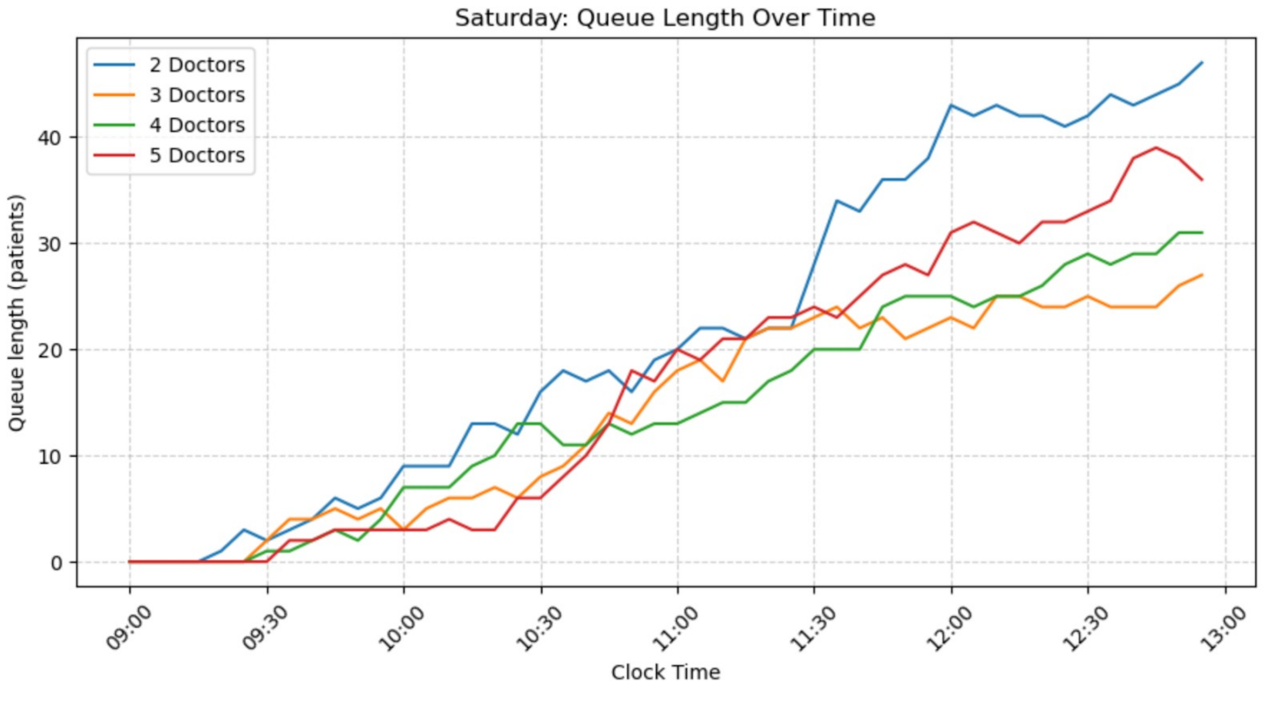


Findings

- Moving from 2 to 3 doctors reduces waiting time by more than half (66.4 → 30.9 minutes) while maintaining reasonable utilization (79.3%).
- Additional doctors beyond 3 provide minimal improvement.

Simulation Results - Saturday

Doctors	Average Wait (min)	Utilization (%)	Assessment
2	**57.7**	**93.4%**	✅ **Cost Optimal**
3	38.0	91.3%	⚠ Service Level Trade-off
4	36.6	90.8%	✖ Overcapacity
5	38.7	90.2%	✖ Excessive Capacity



Findings

- 2 doctors provide cost-effective service
- 3 doctors improve service but increase cost
- Policy decision: cost vs. service level. Target: ≤45 minutes justifies 3 doctors

Cost Analysis Framework

Total Cost Model

```
Total Daily Cost (TC) = CD + CS + CW
CD: Staff cost (doctors, nurses, receptionists)
CS: Space and operational overhead
CW: Waiting cost proportional to average queue length
```

Cost Parameters (JPY)

Staff Costs

Role	Weekday Rate	Saturday Rate
Doctor	¥16,000/hour	¥75,000/hour
Nurse	¥3,000/hour	¥3,000/hour
Receptionist	¥2,250/hour	¥2,250/hour

Fixed Daily Costs

¥102K

Weekday Fixed Cost

¥51K

Saturday Fixed Cost

Includes: Utilities, facilities, support staff

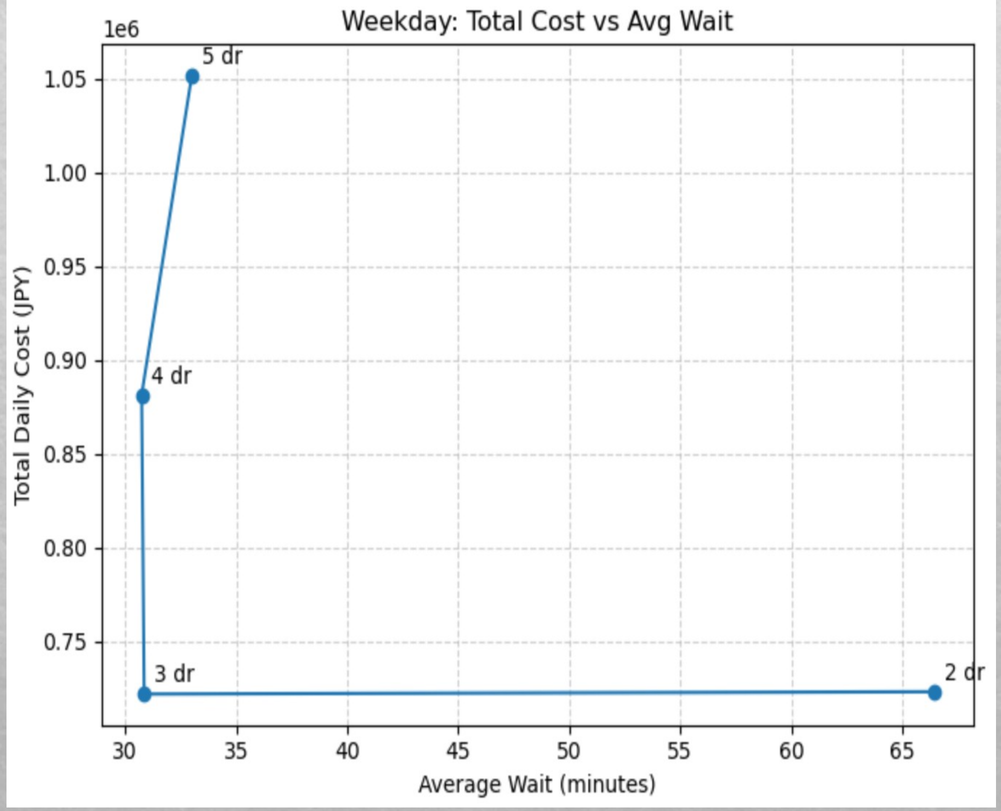
Patient Waiting Cost

Base Rate: ¥2,000 per patient-hour

Represents the monetary equivalent of patient time value: Lost productivity during waiting, opportunity cost of time, patient satisfaction impact, potential revenue loss from dissatisfied patients

Cost Results - Weekday

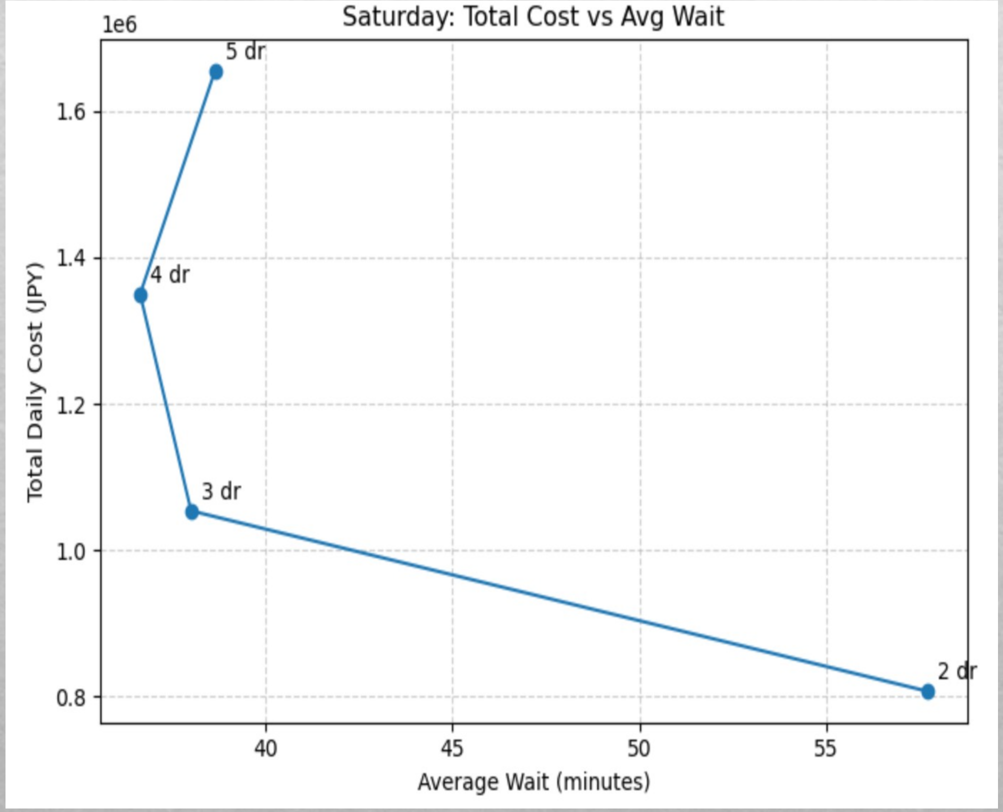
Doctors	Doctor Cost	Fixed Cost	Waiting Cost	Total Cost	Assessment
2	¥320,000	¥102,000	¥301,085	¥723,085	High waiting penalty
3	**¥480,000**	**¥102,000**	**¥139,857**	**¥721,857**	✅ **Optimal**
4	¥640,000	¥102,000	¥139,351	¥881,351	Diminishing returns
5	¥800,000	¥102,000	¥149,589	¥1,051,589	Excessive capacity



Adding a third doctor reduces waiting penalties by ¥161,228, which more than offsets the additional staff cost of ¥160,000. This creates the cost optimum at 3 doctors.

Cost Results - Weekday

Doctors	Doctor Cost	Fixed Cost	Waiting Cost	Total Cost	Assessment
2	**¥600,000**	**¥51,000**	**¥155,827**	**¥806,827**	**✓ Cost Optimal**
3	¥900,000	¥51,000	¥102,625	¥1,053,625	Service level trade-off
4	¥1,200,000	¥51,000	¥98,949	¥1,349,949	Overcapacity



The analysis shows that while 2 doctors is cost-optimal at ¥806,827, upgrading to 3 doctors reduces patient wait times to 38 minutes for a premium of ¥246,798, with the final decision depending on the clinic's service level priorities.

Sensitivity Analysis

Waiting Cost Sensitivity

Waiting Cost/Hour	Weekday Optimal	Saturday Optimal	Interpretation
¥1,000	2 Doctors	2 Doctors	Low patient time value
¥2,000	**3 Doctors**	**2 Doctors**	**Base case scenario**
¥3,000	3 Doctors	2 Doctors	High patient time value
¥4,000	3 Doctors	2 Doctors	Premium patient time value

Weekday Sensitivity

Sensitive to waiting cost valuation
Threshold at ¥2,000/hour
Higher congestion drives sensitivity
Robust recommendation: 3 doctors

Saturday Stability

Stable across all waiting cost scenarios
Consistently recommends 2 doctors
Lower congestion reduces sensitivity
Cost structure dominates decision

The optimal staffing recommendations are robust under moderate variations in waiting cost assumptions. Weekday operations show higher sensitivity due to greater congestion, while Saturday results remain stable across all reasonable parameter ranges.

Hybrid Workflow Design

Process Innovation Rationale

Identified Bottlenecks

- Arrival congestion: 09:30-12:00 and 16:00-18:00
- Sequential service dependency
- No overlapping preparation or discharge
- Unpredictable walk-in arrivals

Design Solutions

- Hybrid scheduling: 50% reserved, 50% walk-in
- Parallel nurse-assisted preparation
- Smoother arrival distribution
- Reduced service time variability

Parameters

Scheduling Mix

50%

Reserved Appointments

50%

Walk-in Slots

Service Time Improvement

20%

Faster Service

Through parallel nurse preparation

Arrival Smoothing

25%

Reduced Variability

Via structured scheduling

Hybrid Workflow Design Results

Performance Improvements

Scenario	Doctors	Baseline Wait	Hybrid Wait	Improvement	Utilization Change
Weekday	2	66.4 min	60.9 min	-8.3%	93.1% → 74.7%
	3	**30.9 min**	**23.6 min**	**-23.6%**	**79.3% → 53.8%**
Saturday	2	57.7 min	40.9 min	-29.1%	93.4% → 78.5%
	3	38.0 min	30.5 min	-19.7%	91.3% → 73.1%

Key Achievements

- 20-30% reduction in average waiting times
- Flatter queue profiles throughout the day
- Reduced peak-hour congestion
- More predictable service experience

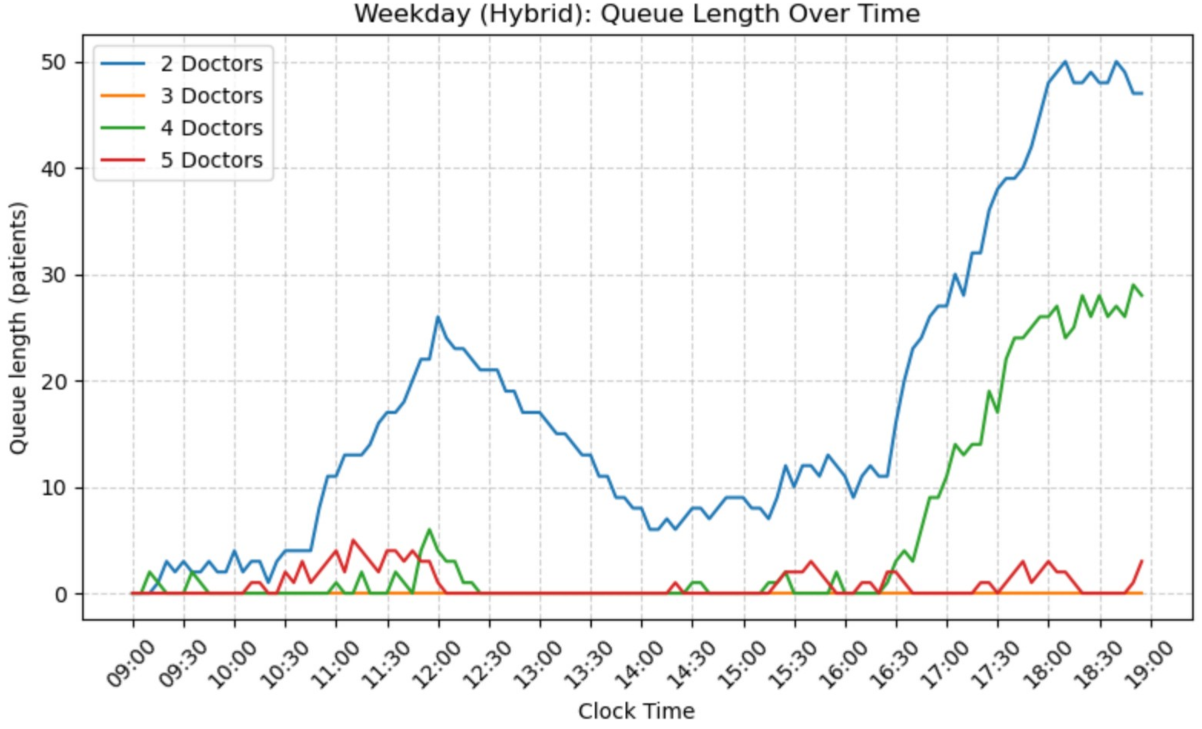
Utilization Impact

- Lower utilization due to smoother flow
- Reduced stress on staff and patients
- Better capacity for handling peaks
- Improved work-life balance for doctors

hybrid workflow demonstrates process redesign can deliver service improvements comparable to adding one physician, without proportional increases in operating cost.

Hybrid Workflow Design Results

```
=== Hybrid Reservation Workflow: Weekday ===
Weekday (Hybrid): 2 doctors → Avg wait 60.9 min | Util 74.7%
Weekday (Hybrid): 3 doctors → Avg wait 23.6 min | Util 53.8%
Weekday (Hybrid): 4 doctors → Avg wait 25.6 min | Util 61.9%
Weekday (Hybrid): 5 doctors → Avg wait 30.8 min | Util 60.1%
```




```
=== Hybrid Reservation Workflow: Saturday ===
Saturday (Hybrid): 2 doctors → Avg wait 40.9 min | Util 78.5%
Saturday (Hybrid): 3 doctors → Avg wait 30.5 min | Util 73.1%
Saturday (Hybrid): 4 doctors → Avg wait 30.3 min | Util 76.5%
Saturday (Hybrid): 5 doctors → Avg wait 26.1 min | Util 74.2%
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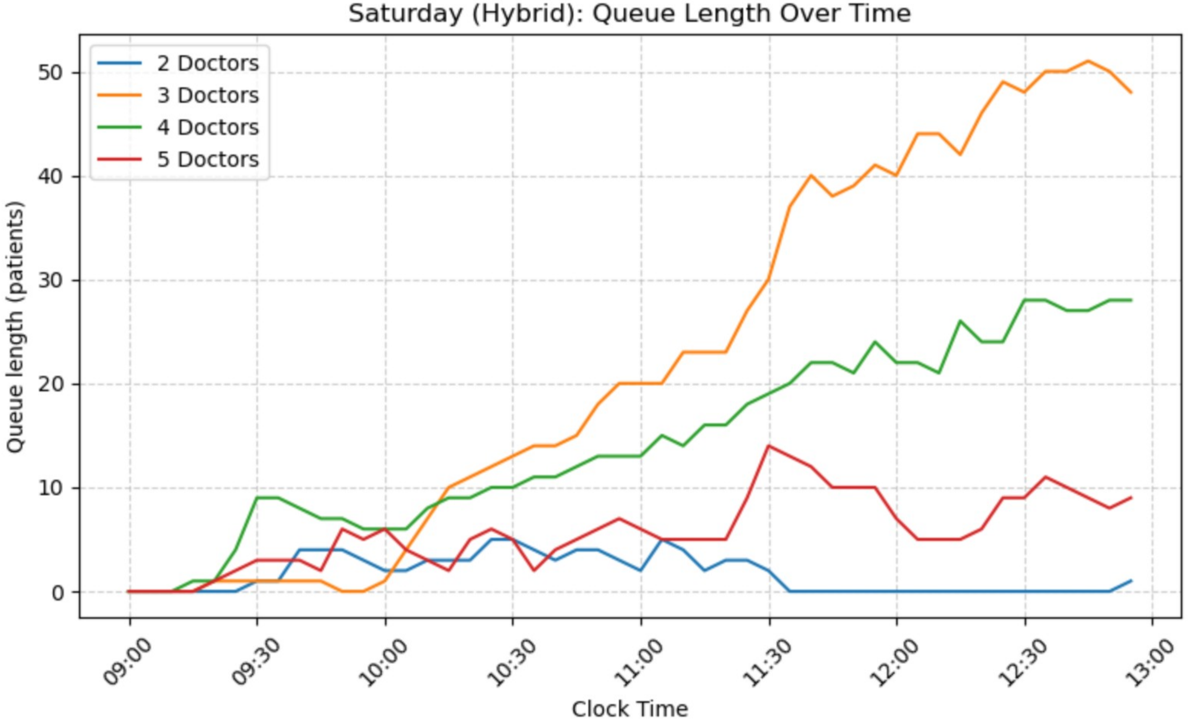

Hybrid Workflow Design Results

Annual Benefits

Reduced waiting costs: ~¥15M/year

Improved patient satisfaction

Potential revenue increase: 10-15%

ROI payback: <3 months

Implementation Costs

Scheduling system setup: ~¥500K one-time

Staff training: ~¥200K

Process redesign: ~¥300K

Total implementation: ~¥1M

Proposed Implementation Roadmap

Phase 1: Immediate Actions (Month 1-2)

Staffing Optimization

- Implement 3-doctor weekday schedule
- Maintain 2-doctor Saturday schedule
- Adjust nurse and receptionist schedules
- Monitor initial performance metrics

System Preparation

- Procure scheduling software
- Design appointment booking system
- Train reception staff on new processes
- Develop patient communication materials

Phase 2: Hybrid Workflow Pilot (Month 3-4)

Pilot Implementation

- Launch 50/50 reservation-walk-in system
- Implement parallel nurse preparation protocols
- Monitor queue patterns and patient feedback
- Adjust scheduling intervals based on initial results
- Train medical staff on new workflow procedures

Phase 3: Full Deployment & Optimization (Month 5-6)

Limitations

Key Limitations

- Simulated rather than empirical arrival data
- Uniform doctor productivity assumption
- No-show rate not explicitly modeled
- Emergency cases not considered
- Spatial constraints simplified

Validation Approach

- Domain expert review (member experience)
- Literature-based parameter validation
- Sensitivity analysis across key variables
- Conservative improvement estimates
- Pilot testing before full implementation

Conclusions

Our study determined that the optimal staffing configuration is **3 doctors on weekdays** (achieving 30.9 minutes average wait time with 79% utilization) and **2 doctors on Saturdays** (providing cost-effective service).

The **hybrid reservation workflow system** reduces patient waiting times by 20-30% without requiring additional staffing, delivering performance improvements equivalent to adding one physician. This demonstrates that intelligent process optimization can substitute for resource expansion, yielding sustainable efficiency gains at significantly lower cost.

The integrated decision analytics framework combining **linear programming, discrete-event simulation, and workflow redesign** provides a replicable methodology for healthcare resource optimization. Implementation of the hybrid reservation system with optimal staffing offers a pragmatic, evidence-based solution for clinics seeking to balance operational efficiency, cost control, and patient satisfaction in resource-constrained healthcare environments.

Thank you!