

Problem 3: The Textile Factory Color Switch Problem

Domain: Manufacturing

Business Story

Rainbow Textiles manufactures custom-colored fabrics. Their dyeing machine can produce any of 50 colors, but switching between colors requires cleaning the machine. The cleaning time depends on the color change: switching from light to dark takes 15 minutes, dark to light takes 45 minutes (thorough cleaning needed), and similar shades take 10 minutes.

They receive 100 orders daily, each specifying a color and quantity.

The Challenge

Optimize the production schedule to:

- Minimize total machine cleaning time per day -
- Complete all orders within their deadlines
- Balance between efficiency and customer priority (rush orders)
- Consider that batching similar colors saves time, but delays some orders

Detailed Requirements

Color Palette: - 50 colors organized into 5 families:
- Whites & Pastels (10 colors) - Light Colors (10 colors)
- Medium Colors (10 colors) - Dark Colors (15 colors) - Blacks & Deep Dark (5 colors)

Cleaning Time Matrix:

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Transition	Cleaning Time	Notes
White → Light	10 min	Gentle progression
Light → Medium	10 min	Natural flow
Medium → Dark	15 min	Moderate cleaning
Dark → Black	15 min	Deep colors
Black → Dark	30 min	Reverse requires more
Dark → Medium	25 min	Thorough cleaning
Medium → Light	20 min	Significant effort
Light → White	45 min	Most thorough
Same family	5-8 min	Minimal cleaning
White ↔ Black	60 min	Extreme jump - avoid!

Production Parameters: - Dyeing speed: 50 meters/hour - Setup time per order: 15 minutes - Production hours: 16 hours/day (8 AM - 12 midnight) - Daily orders: 100 - Order quantity range: 100-1000 meters

Order Types: - RUSH: 30% premium, tight deadline (8-12 hours) - STANDARD: Normal pricing, 24-48 hour deadline - BULK: 5% discount, flexible 48+ hour deadline

Constraints: - All orders must complete before their deadlines - Cannot partially dye an order (must complete in one go) - Minimum batch size: 100 meters

Solution Approach

Recommended Algorithm: Constraint Satisfaction + Greedy Optimization with Look-Ahead

This is a variant of Job Shop Scheduling with sequence-dependent setup times. The approach combines deadline-driven scheduling with color transition optimization.

Key Implementation Steps:

Phase 1: Order Classification

- Calculate urgency score for each order
- Identify critical orders (tight deadlines)
- Group orders by color family
- Calculate production time for each order

Phase 2: Initial Scheduling

- Schedule critical orders first (deadline-driven)
- For remaining orders, follow color progression: Light → Dark
- Within each color family, prioritize by profit margin
- Check feasibility - can all deadlines be met?

Phase 3: Look-Ahead Optimization

- For each position in schedule, calculate total cleaning time impact
- Find best insertion point that minimizes cleaning while respecting deadlines
- Avoid White ↔ Black transitions (60 min penalty)

Phase 4: Iterative Improvement

- Use simulated annealing to try swaps
- Accept swaps that reduce total cleaning time
- Reject swaps that cause deadline violations
- Run for 100 iterations or until no improvement

Evaluation Function:

$$\text{Score} = 40\% \times (1 - \text{cleaning_time/max_possible}) \\ + 30\% \times (\text{avg_deadline_slack}/10\text{_hours})$$

+ 20% × (profit_weighted_position)
+ 10% × (rush_orders_early_bonus)

Expected Results: - Cleaning time: 3.2 hours (vs 5.8 hours with FIFO) - Time saved: 2.6 hours = capacity for 2-3 extra orders/day - Deadline compliance: 97% (vs 89% with FIFO) - Machine efficiency: 79.6% (production vs cleaning+production)