Competition - The Bakery Delivery Route

Management Science - Artisan Bakery

Client Briefing: Artisan Bakery

The Morning Delivery Crisis

Master Baker's Message:

"Every morning at 5 AM, our delivery van leaves with fresh bread for 12 cafés across the city. Our driver currently takes over 3 hours using his 'intuition' for the route. The fuel costs are killing us, and worse, some cafés get their bread late.

Three of our premium clients open early at 6:30 AM and absolutely MUST have their bread by then. The others open at 7:00 AM or later. We're spending €80+ daily in excess fuel and labor costs. That's €29,200 per year!

Can you optimize our morning delivery route? We need a solution that handles our early-bird cafés and minimizes total distance. Help us deliver happiness more efficiently!"

The Challenge

Your Mission

Design an optimal delivery route for Artisan Bakery that: 1. Visits all 12 cafés exactly once 2. Prioritizes 3 early-opening cafés (must arrive by 6:30 AM) 3. Minimizes total distance traveled 4. Returns to the bakery

Business Context

- Current situation: 3+ hours, driver's intuition, frequent late deliveries
- Cost structure:
  - Fuel: €1.80 per km
  - Driver: €35 per hour
  - Late penalty: €50 per late delivery (damages reputation)
- Vehicle: One delivery van, 40 km/h average speed in morning traffic

Success Metrics

Your solution will be evaluated on: 1. Total distance (primary metric) 2. Time window compliance (meeting early café deadlines) 3. Solution quality vs. other teams 4. Presentation clarity (can the driver understand it?)

Data & Starter Code

```python
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import math
from datetime import datetime, timedelta

# Set seed for consistency across all teams
np.random.seed(2025)

# Bakery location (city center)
bakery_location = (5.0, 5.0)

# 12 Café locations (x, y) in kilometers from city origin
cafe_locations = [
    (2.1, 8.3),   # Café 1: Sunrise Bistro (EARLY - 6:30 AM)
    (7.8, 9.2),   # Café 2: The Daily Grind
    (9.5, 6.1),   # Café 3: Café Europa (EARLY - 6:30 AM)
    (8.4, 2.3),   # Café 4: Corner Coffee
    (4.6, 1.1),   # Café 5: South Side Café
    (1.3, 1.8),   # Café 6: West End Espresso
    (0.7, 4.9),   # Café 7: Riverside Roast
    (1.9, 7.1),   # Café 8: Morning Glory (EARLY - 6:45 AM)
    (3.8, 8.9),   # Café 9: Hilltop Haven
    (6.2, 7.4),   # Café 10: Central Perk
    (7.1, 4.2),   # Café 11: Midtown Munch
    (3.3, 3.7),   # Café 12: Old Town Oven
]

# Café names and opening times
cafe_info = pd.DataFrame({
    'cafe_id': range(1, 13),
    'name': [
        'Sunrise Bistro', 'The Daily Grind', 'Café Europa', 'Corner
Coffee',
        'South Side Café', 'West End Espresso', 'Riverside Roast', 'Morning
Glory',
        'Hilltop Haven', 'Central Perk', 'Midtown Munch', 'Old Town Oven'
    ],
    'x': [loc[0] for loc in cafe_locations],
    'y': [loc[1] for loc in cafe_locations],
    'opening_time': [
        '06:30', '07:00', '06:30', '07:15',   # Cafés 1-4
        '07:30', '07:00', '07:00', '06:45',   # Cafés 5-8
        '07:15', '07:00', '07:30', '07:00'    # Cafés 9-12
    ],
    'time_window': [
        'EARLY', 'Regular', 'EARLY', 'Regular',   # Cafés 1-4
        'Regular', 'Regular', 'Regular', 'EARLY',   # Cafés 5-8
        'Regular', 'Regular', 'Regular', 'Regular'   # Cafés 9-12
    ]
})

# Display the café information
print("CAFÉ INFORMATION:")
```

```python
print("=" * 60)
print(cafe_info.to_string(index=False))
print("\n" + "=" * 60)
print(f"Bakery location: {bakery_location}")
print(f"Departure time: 5:00 AM")
print(f"Average speed: 40 km/h")
print("\nEARLY cafés (must arrive before opening):")
for _, row in cafe_info[cafe_info['time_window'] == 'EARLY'].iterrows():
    print(f"  - {row['name']} (Café {row['cafe_id']}): Opens at
{row['opening_time']}")
```

```
CAFÉ INFORMATION:
============================================================
 cafe_id              name   x   y opening_time time_window
       1    Sunrise Bistro 2.1 8.3        06:30       EARLY
       2   The Daily Grind 7.8 9.2        07:00     Regular
       3       Café Europa 9.5 6.1        06:30       EARLY
       4     Corner Coffee 8.4 2.3        07:15     Regular
       5   South Side Café 4.6 1.1        07:30     Regular
       6 West End Espresso 1.3 1.8        07:00     Regular
       7   Riverside Roast 0.7 4.9        07:00     Regular
       8     Morning Glory 1.9 7.1        06:45       EARLY
       9     Hilltop Haven 3.8 8.9        07:15     Regular
      10      Central Perk 6.2 7.4        07:00     Regular
      11     Midtown Munch 7.1 4.2        07:30     Regular
      12     Old Town Oven 3.3 3.7        07:00     Regular

============================================================
Bakery location: (5.0, 5.0)
Departure time: 5:00 AM
Average speed: 40 km/h

EARLY cafés (must arrive before opening):
  - Sunrise Bistro (Café 1): Opens at 06:30
  - Café Europa (Café 3): Opens at 06:30
  - Morning Glory (Café 8): Opens at 06:45
```

Helper Functions Provided

```python
def calculate_distance(point1, point2):
    """Calculate Euclidean distance between two points."""
    return np.sqrt((point2[0] - point1[0])**2 + (point2[1] - point1[1])**2)

def create_distance_matrix(bakery_loc, cafe_locs):
    """Create a distance matrix for all locations."""
    all_locations = [bakery_loc] + cafe_locs
    n = len(all_locations)
    distances = np.zeros((n, n))

    for i in range(n):
        for j in range(n):
            if i != j:
```

```
                distances[i][j] = calculate_distance(all_locations[i], 
all_locations[j])

    return distances

def calculate_route_distance(route, distance_matrix):
    """Calculate total distance for a route (returns to start)."""
    total = distance_matrix[0][route[0]]  # Bakery to first
    for i in range(len(route) - 1):
        total += distance_matrix[route[i]][route[i+1]]
    total += distance_matrix[route[-1]][0]  # Last to bakery
    return total

def calculate_arrival_times(route, distance_matrix, start_time="05:00", 
speed_kmh=40):
    """Calculate arrival time at each café."""
    arrivals = []
    current_time = datetime.strptime(start_time, "%H:%M")

    # Time to first café
    travel_minutes = (distance_matrix[0][route[0]] / speed_kmh) * 60
    current_time += timedelta(minutes=travel_minutes)
    arrivals.append(current_time.strftime("%H:%M"))

    # Time between cafés
    for i in range(len(route) - 1):
        travel_minutes = (distance_matrix[route[i]][route[i+1]] / 
speed_kmh) * 60
        current_time += timedelta(minutes=travel_minutes + 2)  # 2 min 
delivery time
        arrivals.append(current_time.strftime("%H:%M"))

    return arrivals

def check_time_windows(route, distance_matrix, cafe_info):
    """Check if route meets time window constraints."""
    arrivals = calculate_arrival_times(route, distance_matrix)
    violations = []

    for i, cafe_idx in enumerate(route):
        cafe = cafe_info.iloc[cafe_idx - 1]
        arrival = arrivals[i]
        opening = cafe['opening_time']

        if cafe['time_window'] == 'EARLY' and arrival > opening:
            violations.append({
                'cafe': cafe['name'],
                'arrival': arrival,
                'opening': opening,
                'late_by': (datetime.strptime(arrival, "%H:%M") - 
                          datetime.strptime(opening, "%H:%M")).seconds // 
60
            })
```

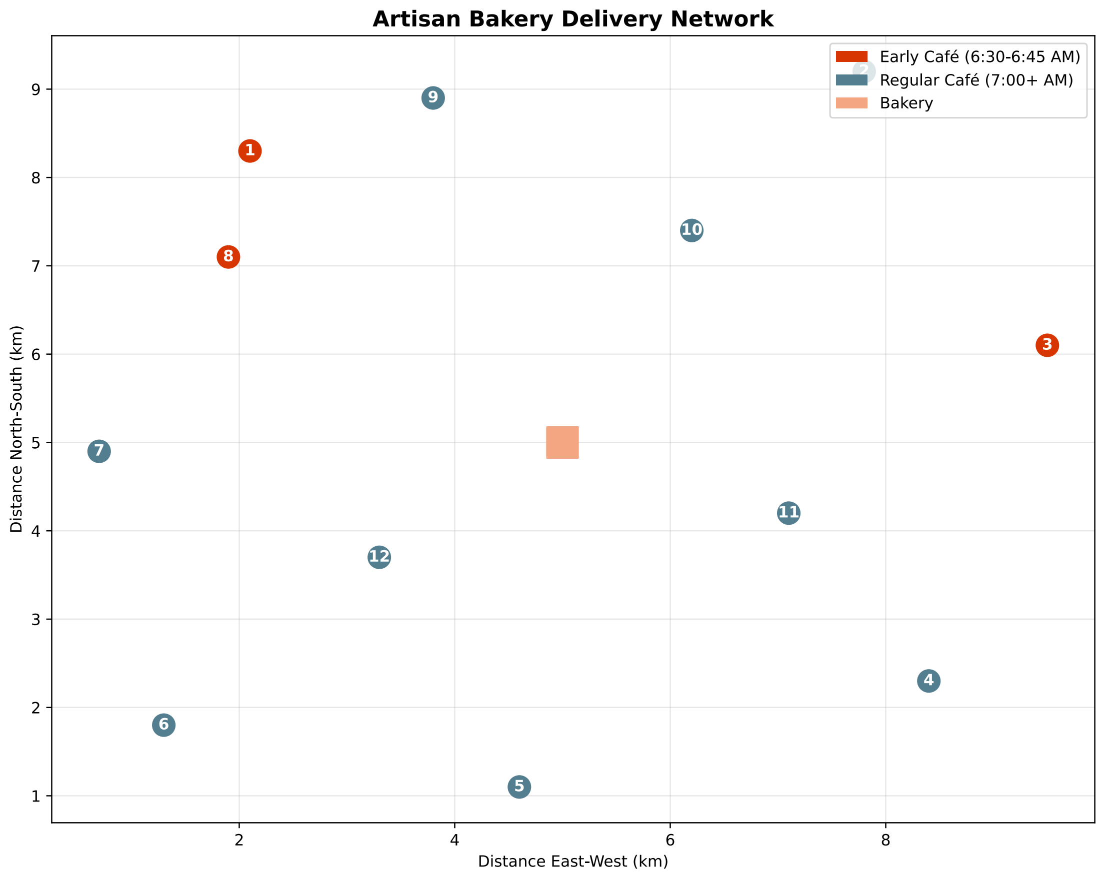
```python
    return violations

# Create distance matrix
distance_matrix = create_distance_matrix(bakery_location, cafe_locations)
print("\nDistance matrix created. Ready to optimize!")
```

```

Distance matrix created. Ready to optimize!
```

Visualization Function

```python
def visualize_route(route, cafe_info, bakery_loc, title="Delivery Route"):
    """Visualize the delivery route on a map."""
    plt.figure(figsize=(10, 8))

    # Plot cafés
    for _, cafe in cafe_info.iterrows():
        color = '#D73502' if cafe['time_window'] == 'EARLY' else '#537E8F'
        plt.scatter(cafe['x'], cafe['y'], s=200, c=color, zorder=3)
        plt.annotate(f"{cafe['cafe_id']}", (cafe['x'], cafe['y']),
                    ha='center', va='center', color='white',
fontweight='bold')

    # Plot bakery
    plt.scatter(bakery_loc[0], bakery_loc[1], s=400, c='#F4A582',
               marker='s', zorder=3, label='Bakery')

    # Plot route if provided
    if route:
        route_x = [bakery_loc[0]]
        route_y = [bakery_loc[1]]
        for cafe_id in route:
            cafe = cafe_info.iloc[cafe_id - 1]
            route_x.append(cafe['x'])
            route_y.append(cafe['y'])
        route_x.append(bakery_loc[0])
        route_y.append(bakery_loc[1])

        plt.plot(route_x, route_y, 'o-', color='gray', linewidth=2,
                markersize=0, alpha=0.6)

        # Add route order annotations
        for i, cafe_id in enumerate(route, 1):
            cafe = cafe_info.iloc[cafe_id - 1]
            plt.annotate(f"#{i}", (cafe['x'], cafe['y']),
                        xytext=(10, 10), textcoords='offset points',
                        fontsize=8, color='black')

    plt.xlabel('Distance East-West (km)')
    plt.ylabel('Distance North-South (km)')
    plt.title(title, fontsize=14, fontweight='bold')
    plt.grid(True, alpha=0.3)
```

```python
    # Legend
    from matplotlib.patches import Patch
    legend_elements = [
        Patch(facecolor='#D73502', label='Early Café (6:30-6:45 AM)'),
        Patch(facecolor='#537E8F', label='Regular Café (7:00+ AM)'),
        Patch(facecolor='#F4A582', label='Bakery')
    ]
    plt.legend(handles=legend_elements, loc='upper right')

    plt.tight_layout()
    plt.show()

# Show the initial problem
visualize_route([], cafe_info, bakery_location, "Artisan Bakery Delivery
Network")
```



Your Task

Required Implementation

Using the provided data and helper functions, implement:

1. Construction Algorithm (choose one or try multiple):
    - Nearest Neighbor (start from bakery)

    - Nearest Neighbor with early cafés first
    - Your own creative approach
2. Improvement Algorithm:
    - 2-opt local search
    - Or another improvement method
3. Time Window Handling:
    - Ensure early cafés are visited before their opening times
    - You may need to modify your algorithm to prioritize these

Template Code Structure

```
# YOUR SOLUTION CODE HERE

def build_initial_route(distance_matrix, cafe_info):
    """
    Build an initial route using your chosen method.

    Args:
        distance_matrix: Distance matrix (13x13, index 0 is bakery)
        cafe_info: DataFrame with café information

    Returns:
        List of café IDs in visit order (1-12)
    """
    # YOUR IMPLEMENTATION
    pass

def improve_route(route, distance_matrix, cafe_info):
    """
    Improve the route using local search.

    Args:
        route: Initial route
        distance_matrix: Distance matrix
        cafe_info: DataFrame with café information

    Returns:
        Improved route
    """
    # YOUR IMPLEMENTATION
    pass

# Build and improve your solution
initial_route = build_initial_route(distance_matrix, cafe_info)
final_route = improve_route(initial_route, distance_matrix, cafe_info)

# Calculate metrics
initial_distance = calculate_route_distance(initial_route, distance_matrix)
final_distance = calculate_route_distance(final_route, distance_matrix)
violations = check_time_windows(final_route, distance_matrix, cafe_info)

# Display results
print("SOLUTION SUMMARY")
```

```python
print("=" * 60)
print(f"Initial route distance: {initial_distance:.2f} km")
print(f"Final route distance: {final_distance:.2f} km")
print(f"Improvement: {initial_distance - final_distance:.2f} km
({(initial_distance - final_distance)/initial_distance*100:.1f}%)")
print(f"\nTime window violations: {len(violations)}")
if violations:
    for v in violations:
        print(f"  - {v['cafe']}: {v['late_by']} minutes late")

print(f"\nEstimated costs:")
print(f"  Fuel: €{final_distance * 1.80:.2f}")
print(f"  Labor: €{(final_distance/40 + 0.2) * 35:.2f}")  # 0.2 hours for
deliveries
print(f"  Penalties: €{len(violations) * 50:.2f}")
print(f"  TOTAL: €{final_distance * 1.80 + (final_distance/40 + 0.2) * 35 +
len(violations) * 50:.2f}")

# Visualize solution
visualize_route(final_route, cafe_info, bakery_location,
               f"Optimized Route: {final_distance:.2f} km")
```

Deliverables

1. Code File

Submit your completed code with: - Your construction algorithm - Your improvement algorithm - Clear comments explaining your approach - Final route and distance

2. One-Slide Presentation (PDF)

Create a single slide containing:

Title: Team Name - Artisan Bakery Route Optimization

Content: - Route visualization (map showing your solution) - Key metrics: - Total distance: ___ km - Time window compliance: ✓ or ✕ for each early café - Daily cost: €

- Method summary (2-3 bullets): - Construction approach used - Improvement method applied - Special handling for time windows - Business impact: - Daily savings: €

- Annual savings: €___

3. Presentation Preparation

Be ready to present (3 minutes): 1. Problem understanding (30 sec): What makes this challenging? 2. Solution approach (1 min): How did you tackle it? 3. Results (1 min): Distance, costs, time compliance 4. Key insight (30 sec): What surprised you or what would you recommend?

Evaluation Rubric

Technical (60%)

- Algorithm correctness (20%): Does it produce valid routes?
- Solution quality (20%): How good is your distance?

- Time window handling (20%): Do early cafés get deliveries on time?

Analysis (25%)

- Metrics calculation (10%): Accurate costs and times
- Improvement achieved (10%): How much better than initial?
- Code clarity (5%): Well-commented and organized

Presentation (15%)

- Visualization quality (5%): Clear route display
- Communication (5%): Can the baker understand your solution?
- Business focus (5%): Emphasis on practical impact

Competition Tips

Strategy Suggestions

1. Quick Win: Start with nearest neighbor, it's simple and often good enough
2. Time Windows First: Consider visiting early cafés first, even if slightly suboptimal
3. Multiple Attempts: Try different starting strategies:
    - Start with closest early café
    - Start with furthest early café
    - Regular nearest neighbor then adjust
4. Improvement Focus: Even basic 2-opt can save 10-20% distance
5. Validation: Always check time windows! A shorter route that's late is worse than a longer route on time.

Common Pitfalls to Avoid

- ❌ Forgetting to return to bakery
- ❌ Not checking time windows until the end
- ❌ Over-optimizing distance at the expense of deadlines
- ❌ Starting from a café instead of the bakery
- ❌ Not testing your solution with the provided check functions

Hints from the Master Baker

"The early bird cafés are my premium clients - they pay 20% more for early delivery. I'd rather drive an extra kilometer than be late to them!"

"My current driver always does the early cafés first, then figures out the rest. Maybe he's onto something?"

"Sometimes the 'shortest' route isn't the best route when you factor in traffic patterns and delivery windows."

Good Luck!

Remember: The goal is a practical solution that the bakery can actually use tomorrow morning. Perfect optimization is less important than reliable, on-time delivery!

Time Limit: 60 minutes in class (continue development at home if needed)

May the best route win! 🥐🚚

Bibliography