Consulting Project: QuickBite Delivery Optimization

Management Science - Food Delivery Logistics

Client Briefing: QuickBite

Meet Your Client

- Industry: Food Delivery / Logistics
- Client Contact: Eliza Chen, CEO
- Company Size: 12 employees, 120+ daily deliveries

The CEO's Dilemma

Eliza Chen, CEO of QuickBite

“We started QuickBite four years ago with a simple mission: deliver restaurant-quality meals to busy citizens in Hamburg. But we're bleeding money on delivery costs while customers complain about cold food!

Right now, our 4 drivers just… wing it. They look at their delivery list each morning and decide their own routes based on ‘intuition.’ The results are terrible:

- 75% of deliveries arrive late
- Customer complaints about cold food: Up 40% this quarter

Our investors are getting nervous. We need to cut delivery costs AND improve on-time delivery. Can you help us design optimal routes that keep food hot and costs low?

We have data from last week's operations. Please show us what's possible!“

The Business Context

Current Operations

- Daily deliveries: 120 meal orders across Hamburg
- Fleet: 4 delivery drivers with insulated cars
- Depot: Central location (Hamburg Hauptbahnhof area)
- Service hours: 11:00 AM - 9:00 PM
- Driver capacity: Each driver can carry up to 35 meals at once

Cost Structure

- Driver wages: €18/hour (including benefits)
- Fuel costs: €0.55 per km
- Late delivery penalty: €5 per late delivery (customer discount)
- Cold food complaints: €10 per complaint

Customer Expectations

- Each delivery has a time window (requested delivery time ± 15 minutes)
- Time window violation = Late penalty + Potential cold food complaint

Your Mission

Design an optimal routing system for QuickBite's 4 drivers that:

1. Minimizes total delivery costs (driver time + fuel + penalties)
2. Maximizes on-time deliveries (arrive within time windows)
3. Respects vehicle capacity (max 35 meals per driver at once)
4. Ensures fairness (balanced workload across drivers)

The Data

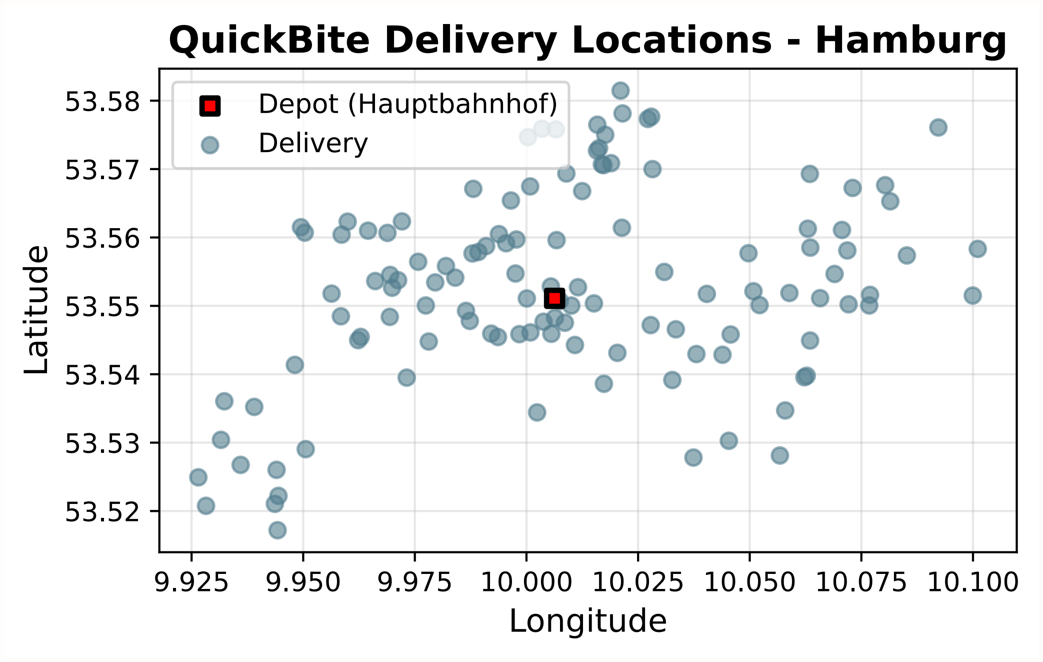
Below is real data from last Tuesday, a typical operating day for QuickBite.

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

# Set random seed for reproducibility
np.random.seed(2025)

# Depot location (Hamburg Hauptbahnhof)
depot = {
    'name': 'QuickBite Depot',
    'lat': 53.5511,
    'lon': 10.0063
}

# Generate 120 delivery locations across Hamburg
# Hamburg spans roughly: lat 53.45-53.65, lon 9.85-10.15
def generate_hamburg_deliveries(n=120):
    deliveries = []

    # Create realistic clusters (residential areas, business districts)
    clusters = [
        {'lat': 53.5511, 'lon': 10.0063, 'n': 30, 'type': 'city_center'},
# Altstadt
        {'lat': 53.5534, 'lon': 9.9700, 'n': 25, 'type': 'residential'},
# Altona
        {'lat': 53.5753, 'lon': 10.0153, 'n': 18, 'type': 'residential'},
# Eppendorf
        {'lat': 53.5580, 'lon': 10.0742, 'n': 20, 'type': 'business'},
# Wandsbek
        {'lat': 53.5252, 'lon': 9.9350, 'n': 12, 'type': 'residential'},
# Bahrenfeld
        {'lat': 53.5440, 'lon': 10.0465, 'n': 15, 'type': 'business'},
# HafenCity
    ]
    delivery_id = 1
    for cluster in clusters:
        for i in range(cluster['n']):
            # Add random variation around cluster center
            lat = np.random.normal(cluster['lat'], 0.008)
            lon = np.random.normal(cluster['lon'], 0.012)

            # Determine time window based on cluster type
            if cluster['type'] == 'business':
                # Business districts: More lunch orders
                hour = np.random.choice([12, 13, 18, 19], p=[0.4, 0.3, 0.2,
0.1])
            else:
                # Residential: More dinner orders
                hour = np.random.choice([12, 13, 18, 19], p=[0.1, 0.2, 0.4,
0.3])

            minute = np.random.randint(0, 60)

            # Time window: ±15 minutes from requested time
            requested_time = f"{hour:02d}:{minute:02d}"
            window_start = f"{hour:02d}:{max(0, minute-15):02d}"
            window_end_min = minute + 15
            window_end_hour = hour + (window_end_min // 60)
            window_end_min = window_end_min % 60
            window_end = f"{window_end_hour:02d}:{window_end_min:02d}"

            deliveries.append({
                'delivery_id': delivery_id,
                'lat': lat,
                'lon': lon,
                'area': cluster['type'],
                'requested_time': requested_time,
                'window_start': window_start,
                'window_end': window_end,
                'order_value': np.random.normal(35, 10)
            })
            delivery_id += 1

    return pd.DataFrame(deliveries)

# Generate delivery data
deliveries_df = generate_hamburg_deliveries(120)

# Display first 10 deliveries
print("QUICKBITE DELIVERY DATA - Tuesday, Nov 19, 2024")
print("=" * 80)
print(deliveries_df.head(10).to_string(index=False))
print(f"\n... and {len(deliveries_df) - 10} more deliveries")
print("\n" + "=" * 80)
print(f"Total deliveries: {len(deliveries_df)}")
print(f"Total order value: €{deliveries_df['order_value'].sum():.2f}")
```

```
QUICKBITE DELIVERY DATA - Tuesday, Nov 19, 2024
================================================================================
 delivery_id       lat       lon        area requested_time window_start
window_end  order_value
           1 53.550361 10.015111 city_center          18:22        18:07
18:37    44.387576
           2 53.545443  9.993619 city_center          18:03        18:00
18:18    31.338218
           3 53.557661  9.987915 city_center          19:09        19:00
19:24    42.862084
           4 53.539506  9.973181 city_center          18:31        18:16
18:46    36.461754
           5 53.559608 10.006745 city_center          12:45        12:30
13:00    34.959365
           6 53.559704  9.997752 city_center          19:36        19:21
19:51    39.476978
           7 53.545861  9.998407 city_center          19:04        19:00
19:19    29.864538
           8 53.549267  9.986467 city_center          18:25        18:10
18:40    31.091045
           9 53.552830 10.005464 city_center          19:14        19:00
19:29    54.015407
          10 53.545939  9.992114 city_center          18:06        18:00
18:21    50.522051

... and 110 more deliveries

================================================================================
Total deliveries: 120
Total order value: €4189.24
```

Delivery Visualization

```python
def visualize_deliveries(deliveries_df, depot_location, routes=None):
    """
    Visualize all delivery locations and optional routes.

    Args:
        deliveries_df: DataFrame with delivery information
        depot_location: Dict with 'lat' and 'lon' keys
        routes: Optional list of routes, where each route is a list of
delivery_ids
    """
    plt.figure()

    # Plot depot
    plt.scatter(depot_location['lon'], depot_location['lat'],
                c='red', marker='s', zorder=5,
                label='Depot (Hauptbahnhof)', edgecolors='black',
linewidths=2)

    # Plot all deliveries
    plt.scatter(deliveries_df['lon'], deliveries_df['lat'],
                 c='#537E8F', alpha=0.6, label='Delivery', zorder=3)

    # If routes are provided, draw them
    if routes is not None:
        colors = ['#1f77b4', '#ff7f0e', '#2ca02c', '#d62728']
        for i, route in enumerate(routes):
            if len(route) == 0:
                continue

            # Start from depot
            route_lons = [depot_location['lon']]
            route_lats = [depot_location['lat']]

            # Add delivery points
            for delivery_id in route:
                delivery = deliveries_df[deliveries_df['delivery_id'] ==
delivery_id].iloc[0]
                route_lons.append(delivery['lon'])
                route_lats.append(delivery['lat'])

            # Return to depot
            route_lons.append(depot_location['lon'])
            route_lats.append(depot_location['lat'])

            # Plot route
            plt.plot(route_lons, route_lats,
                     color=colors[i % len(colors)], linewidth=2,
                     alpha=0.7, label=f'Driver {i+1} Route', zorder=2)

    plt.xlabel('Longitude', fontsize=12)
    plt.ylabel('Latitude', fontsize=12)
    plt.title('QuickBite Delivery Locations - Hamburg', fontsize=14,
fontweight='bold')
    plt.legend(loc='upper left', fontsize=10)
    plt.grid(True, alpha=0.3)
    plt.tight_layout()
    plt.show()

# Visualize all deliveries
visualize_deliveries(deliveries_df, depot)
```



Helper Functions (Minimal Code Provided)

I provide only basic helper functions. You must implement the routing algorithms yourself.

```python
def haversine_distance(lat1, lon1, lat2, lon2):
    """
    Calculate distance between two GPS coordinates using Haversine formula.
    Returns distance in kilometers.
    """
    from math import radians, sin, cos, sqrt, atan2

    R = 6371  # Earth's radius in kilometers

    lat1, lon1, lat2, lon2 = map(radians, [lat1, lon1, lat2, lon2])
    dlat = lat2 - lat1
    dlon = lon2 - lon1

    a = sin(dlat/2)**2 + cos(lat1) * cos(lat2) * sin(dlon/2)**2
    c = 2 * atan2(sqrt(a), sqrt(1-a))

    return R * c

def create_distance_matrix(deliveries_df, depot_location):
    """
    Create distance matrix for all locations (depot + all deliveries).
    Returns numpy array where index 0 is depot, indices 1-120 are
deliveries.
    """
    n = len(deliveries_df) + 1  # +1 for depot
    distances = np.zeros((n, n))
    # Depot distances
    for i, row in deliveries_df.iterrows():
        dist = haversine_distance(depot_location['lat'],
depot_location['lon'],
                                  row['lat'], row['lon'])
        distances[0, i+1] = dist
        distances[i+1, 0] = dist

    # Delivery-to-delivery distances
    for i, row1 in deliveries_df.iterrows():
        for j, row2 in deliveries_df.iterrows():
            if i != j:
                dist = haversine_distance(row1['lat'], row1['lon'],
                                        row2['lat'], row2['lon'])
                distances[i+1, j+1] = dist

    return distances

# Create distance matrix
distance_matrix = create_distance_matrix(deliveries_df, depot)
print(f"\nDistance matrix created: {distance_matrix.shape}")
print(f"Example: Depot to Delivery #1 = {distance_matrix[0, 1]:.2f} km")
```

```

Distance matrix created: (121, 121)
Example: Depot to Delivery #1 = 0.59 km
```

Cost Calculation Function

```
def calculate_route_cost(route, deliveries_df, distance_matrix,
depot_location):
    """
    Calculate total cost for a single route.

    Args:
        route: List of delivery_ids in visit order
        deliveries_df: DataFrame with delivery information
        distance_matrix: Numpy array of distances
        depot_location: Dict with depot location

    Returns:
        dict with cost breakdown
    """
    if len(route) == 0:
        return {'total_cost': 0, 'distance': 0, 'time': 0,
'late_penalties': 0}

    # Constants
    DRIVER_WAGE = 18  # €/hour
    FUEL_COST = 0.55  # €/km
    LATE_PENALTY = 5  # €/delivery
    COLD_FOOD_COST = 10  # €/delivery (if late > 60 minutes)
    AVG_SPEED = 25    # km/h (Hamburg traffic)
    SERVICE_TIME = 3  # minutes per delivery

    total_distance = 0
    total_time = 0  # minutes
    late_count = 0
    cold_food_count = 0
    current_time = datetime.strptime("11:00", "%H:%M")  # Start time

    # Depot to first delivery
    first_delivery_id = route[0]
    first_idx = deliveries_df[deliveries_df['delivery_id'] ==
first_delivery_id].index[0]
    total_distance += distance_matrix[0, first_idx + 1]
    travel_time = (distance_matrix[0, first_idx + 1] / AVG_SPEED) * 60  #
minutes
    current_time += timedelta(minutes=travel_time)

    # Check delivery time window
    delivery_info = deliveries_df.iloc[first_idx]
    window_start = datetime.strptime(delivery_info['window_start'], "%H:
%M")
    window_end = datetime.strptime(delivery_info['window_end'], "%H:%M")

    # If arrived early, wait until window opens
    if current_time.time() < window_start.time():
        wait_time = (window_start.hour * 60 + window_start.minute) -
(current_time.hour * 60 + current_time.minute)
        total_time += wait_time
        current_time = window_start

    # Check if late
    if current_time.time() > window_end.time():
        late_count += 1
        # Check if late by more than 60 minutes (cold food complaint)
        late_minutes = (current_time.hour * 60 + current_time.minute) -
(window_end.hour * 60 + window_end.minute)
        if late_minutes > 60:
            cold_food_count += 1

    current_time += timedelta(minutes=SERVICE_TIME)
    total_time += SERVICE_TIME

    # Delivery to delivery
    for i in range(len(route) - 1):
        from_id = route[i]
        to_id = route[i + 1]

        from_idx = deliveries_df[deliveries_df['delivery_id'] ==
from_id].index[0]
        to_idx = deliveries_df[deliveries_df['delivery_id'] ==
to_id].index[0]

        dist = distance_matrix[from_idx + 1, to_idx + 1]
```

```python
        total_distance += dist

        travel_time = (dist / AVG_SPEED) * 60
        current_time += timedelta(minutes=travel_time)

        # Check delivery time window
        delivery_info = deliveries_df.iloc[to_idx]
        window_start = datetime.strptime(delivery_info['window_start'],
"%H:%M")
        window_end = datetime.strptime(delivery_info['window_end'], "%H:
%M")

        # If arrived early, wait until window opens
        if current_time.time() < window_start.time():
            wait_time = (window_start.hour * 60 + window_start.minute) -
(current_time.hour * 60 + current_time.minute)
            total_time += wait_time
            current_time = window_start

        # Check if late
        if current_time.time() > window_end.time():
            late_count += 1
            # Check if late by more than 60 minutes (cold food complaint)
            late_minutes = (current_time.hour * 60 + current_time.minute) -
(window_end.hour * 60 + window_end.minute)
            if late_minutes > 60:
                cold_food_count += 1

        current_time += timedelta(minutes=SERVICE_TIME)
        total_time += SERVICE_TIME

    # Return to depot
    last_delivery_id = route[-1]
    last_idx = deliveries_df[deliveries_df['delivery_id'] ==
last_delivery_id].index[0]
    total_distance += distance_matrix[last_idx + 1, 0]
    travel_time = (distance_matrix[last_idx + 1, 0] / AVG_SPEED) * 60
    total_time += travel_time

    # Calculate costs
    driver_cost = DRIVER_WAGE * (total_time / 60)  # Convert minutes to
hours
    fuel_cost = FUEL_COST * total_distance
    penalty_cost = LATE_PENALTY * late_count
    cold_food_cost = COLD_FOOD_COST * cold_food_count

    return {
        'total_cost': driver_cost + fuel_cost + penalty_cost +
cold_food_cost,
        'driver_cost': driver_cost,
        'fuel_cost': fuel_cost,
        'penalty_cost': penalty_cost,
        'cold_food_cost': cold_food_cost,
        'distance': total_distance,
        'time': total_time,
        'late_count': late_count,
        'cold_food_count': cold_food_count,
        'on_time_rate': 1 - (late_count / len(route)) if len(route) > 0
else 1.0
    }

# Example: Calculate cost for a simple route
example_route = [1, 2, 3, 4, 5]
example_cost = calculate_route_cost(example_route, deliveries_df,
distance_matrix, depot)
print("\nExample route cost breakdown:")
for key, value in example_cost.items():
    print(f"  {key}: {value:.2f}")
```

```

Example route cost breakdown:
  total_cost: 170.40
  driver_cost: 144.98
  fuel_cost: 5.42
  penalty_cost: 10.00
  cold_food_cost: 10.00
  distance: 9.86
  time: 483.27
  late_count: 2.00
  cold_food_count: 1.00
  on_time_rate: 0.60
```

Your Task

You must develop a routing solution that assigns all 120 deliveries to 4 drivers and provides:

1. Jupyter Notebook with Complete Solution

Your notebook should include:

- Data exploration: Visualizations and insights about delivery patterns
- Algorithm implementation: Your routing approach (construction + improvement)
- Results: Final routes for all 4 drivers with cost breakdown
- Analysis: Comparison to a baseline (e.g. random assignment)

> **Note**
>
> I won't judge the code quality in this notebook. It's just for me to review your final solution and identify any mistakes if your results seem unrealistic. The final project will be graded primarily based on your presentation and the results you have achieved.

2. Presentation
- Problem understanding: Eliza's pain points in your own words
- Your approach: Algorithm choice and justification
- Results: Routes visualization, cost savings, on-time improvement
- Business impact: Recommendations for QuickBite

ℹ Note

Please upload both, presentation and jupyter notebook (or `.py` files) for the final project.

3. Key Metrics to Report
- Total cost (all 4 drivers combined)
- Total distance traveled
- On-time delivery rate (% within time windows)
- Number of late deliveries
- Driver workload balance (fairness)
- Cost savings vs. current system (estimate baseline first!)

Constraints and Requirements

! Important

Hard Constraints (Must Satisfy)

1. All deliveries assigned: Every delivery must be assigned to exactly one driver
2. Vehicle capacity: Each driver can carry max 35 meals at once
3. Start and end at depot: All routes begin and end at the depot
4. Time feasibility: Deliveries should be attempted within operating hours (11:00-21:00)

Soft Constraints (Optimize)

1. Minimize total cost (driver time + fuel + late penalties + cold food costs)
2. Maximize on-time delivery rate
3. Balance workload across drivers (fairness)

Tips for Success

1. Capacity matters: With 120 deliveries and 35-meal capacity, you will need to use all drivers. This affects your algorithm design!
2. Time windows are critical: Late penalties and cold food complaints are expensive. Sometimes driving extra distance to be on time is worth it.
3. Clustering helps: Hamburg has natural neighborhood clusters. Use them!
4. Visualize early: Plot routes as you develop them. Bad routes are obvious visually.
5. Start simple: Get a working solution first, then optimize.

6. Fairness counts: Drivers will quit if workload is unfair. Balance is important. :::

Common Pitfalls to Avoid

- Ignoring capacity: Don't create routes with 40 deliveries for one driver!
- Forgetting to return to depot: Routes must be round-trips
- Not checking time windows: Validate after every algorithmic change
- Over-optimization: A good solution with clear explanation beats a "perfect" black box
- Poor visualization: Make sure your routes are clearly visible and understandable
- No baseline comparison: Always show improvement vs. current system!

Data Access

All data is provided in this notebook:

- `deliveries_df`: DataFrame with 120 deliveries
- `depot`: Dict with depot location
- `distance_matrix`: Numpy array of distances
- Helper functions: `calculate_route_cost()`, `visualize_deliveries()`

You may add additional functions as needed!

Deadline

- Notebook submission & Presentation: Lecture 12
- Good luck, consultants!

Bibliography