**A case study: Last-Mile Delivery Optimization in Dubai**

**1. The Problem**

* Rapid E-Commerce Growth & Delivery Challenges
  + - * + Dubai’s booming e-commerce market has created a need for swift, reliable delivery services. Fulfilment centres (FCs) and warehouses often have to dispatch orders to numerous drop-off points, all while contending with heavy traffic at different times of the day.
* Key Pain Points
  + - * + Unpredictable Traffic Delays: Rush hours or accident-prone roads can significantly delay shipments.
        + Rising Operational Costs: Longer routes mean higher fuel usage and increased CO₂ emissions.
        + Multiple Fulfilment Centres & Drivers: Coordinating which driver handles which deliveries, and balancing workload, can be difficult.
* Why Address It?
  + - * + Customer Expectations are skyrocketing, with many wanting same-day or next-day delivery.
        + Cost Efficiency is vital for competitive pricing.
        + Environmental Responsibility is increasingly important, prompting businesses to reduce their carbon footprint.

**2. Rationale & Goals**

* What Needed to Be Solved
  + - * + Inefficient Routes leading to wasted time and higher costs.
        + Driver Overload when one FC or driver is assigned too many deliveries.
        + Static Routing ignoring real-time changes in road conditions.
* Core Objectives
  + - * + Minimize Delivery Times & Distances: Shorter routes benefit both cost and customer satisfaction.
        + Balance Workload: Ensure no single driver or FC is overloaded.
        + Incorporate Real-Time Traffic: Adjust speeds to reflect TomTom live data, reducing traffic-related delays.
        + Provide an Easy Visualization: A Streamlit dashboard to show routes, metrics, and key insights in a user-friendly manner.

**3. Approach & Methodology**

* **The Strategy**

1. Data Acquisition:
   * + - * Geocode addresses for warehouses, FCs, and delivery points.
         * Retrieve live traffic speeds from TomTom’s API for each coordinate.
2. Algorithmic Core:
   * + - * A Vehicle Routing Problem (VRP) approach to allocate deliveries to multiple drivers.
         * Within each driver’s set, a TSP (Traveling Salesman Problem) solver finds a near-optimal route sequence.
         * We use clustering so that deliveries are grouped logically, avoiding a single huge TSP problem.
3. Real-Time Graph Update:
   * + - * With OSMnx and NetworkX, each road segment is assigned a dynamic “travel\_time” based on TomTom speeds, making the routing realistic for current conditions.
4. Performance Tracking:
   * + - * Calculate fuel cost, CO₂ emissions, and overall delivery time.
         * Compare optimized routes vs. a naive baseline to measure improvements.
5. Why VRP + TSP?
   * + - * VRP handles multiple drivers and capacity constraints.
         * TSP sequences delivery stops effectively once we know which driver is handling which deliveries.
         * Real-time traffic updates improve on typical static VRP solutions.

**4. Implementation Details**

* + 1. **Key Components**
       - AdvancedVRP.py:

Geocoding and traffic fetching from TomTom.

solve\_vrp\_clustering(): Divides deliveries among drivers via clustering.

run\_cluster\_tsp(): Approximates TSP for each cluster.

run\_vrp(): Orchestrates everything, builds a Folium map showing routes, and returns key metrics.

* + 1. **ProjectDashboard.py:**
       - * Streamlit app that calls run\_vrp().
         * Displays the map (ExpandedDubai\_VRP.html), an interactive legend, and top-level KPI metrics.
         * Sidebar charts (Altair) for driver distance, delivery times, and a pie chart for FC utilization.
         * Collapsible “Key Insights” sections explaining real-time traffic benefits, environmental impact, workload balancing, and delivery efficiency.

**The Dashboard Layout**

* Top: Title and short overview.
* Center: Map with color-coded routes, each driver in a distinct color. Hover tooltips for “Leg Distance” & “Leg Time.”
* Right: A “Map Overview” box showing average time & disclaimers, plus a “Legend” box describing icons and route colors.
* Below Map: KPI metrics (distance, average time, CO₂ saved, fuel cost).
* Left Sidebar:
  + - * + Driver charts (distance/time).
        + Fulfillment center pie chart.
        + Collapsible expansions for Key Insights.

**5. Conclusion: How the Problem Was Solved**

**By combining real-time traffic data with an efficient VRP + TSP approach, the system:**

* + - Minimizes Road Time: Shortens routes and finds better paths even in heavy traffic.
    - Reduces Fuel & Emissions: Fewer kilometres travelled means direct savings and eco-friendly operations.
    - Balances Driver Workload: Clustering ensures no single driver is overloaded while others remain underutilized.
    - Provides Actionable Insights: A Streamlit dashboard highlights performance metrics, driver times, and FC workloads in an intuitive format.

**Final Takeaways:**

* + - Real-time data significantly improves last-mile logistics, saving both time and cost.
    - The dashboard approach ensures clarity for managers or dispatchers to track routes and performance.
    - The solution is scalable and can adapt to more locations, more drivers, or different traffic APIs if needed.
    - This project showcases a holistic approach to last-mile delivery optimization, from problem definition to a visually appealing, data-driven result.