Large-Scale Optimization of Last-Mile Drone Delivery Network: Column Generation to Solve a VRP-D

Optimizing emergency responses: developing operations research tools for Flood response in Bangladesh

Date: Sep 02, 2024

- For now, we are focusing on Case Study 1. So, you can skip next few slides and concentrate from Slides 08-14

Research Outline

- Introduction
  - Background
  - RQ
- Method
  - Proposed methodology
  - Solution algorithm
- Computational Result
- Discussion

Background & Motivation

- Last-mile delivery is the most time-consuming and costly part of the supply chain, making its optimization crucial for competitive advantage.
- To meet rising e-commerce demands, logistics companies are turning to innovative solutions like drone delivery to improve efficiency.
- This paper addresses the challenges of optimizing large-scale last-mile drone delivery by using a column generation approach to solve the Vehicle Routing Problem with Drone (VRP-D).
- Extensive experiments show that the proposed method improves delivery efficiency and reduces costs, offering valuable insights for optimizing last-mile logistics with advanced technologies.

Research Questions

Model itself

1. What novel mathematical models can be developed to incorporate multi-modal transportation (e.g., combining trucks, drones, bikes) into the VRP for last-mile delivery?
2. How can models for drones be adapted to handle dynamic, real-time conditions, such as sudden changes in delivery locations, or unexpected drone failures?

Solution algorithm

3. How can the pricing problem in column generation be optimized to generate routes more effectively for last-mile delivery?
4. How can heuristics or metaheuristics be integrated with column generation to improve solution quality for last-mile delivery optimization?

Sensitivity

5. What are the impacts of various problem parameters (e.g., number of customers, geographic distribution) on the performance of VRP models for last-mile delivery?
6. What are the trade-offs between solution quality and computational time when using heuristic-based column generation?
7. What are the impacts of varying problem parameters (e.g., number of deliveries, geographic distribution) on the performance of VRP algorithms in drone delivery?

Proposed Method

RQ

a) What novel mathematical models can be developed to incorporate multi-modal transportation (e.g., combining trucks, drones, bikes) into the VRP for last-mile delivery?
b) How can TSP models for drones be adapted to handle dynamic, real-time conditions, such as sudden changes in delivery locations, or unexpected drone failures?

Dataset

++

Optimization modeling

Math programming formulation ++

Solution Algorithm

Column Generation

1. Master Problem
2. Sub problem

Solution algorithm

- Column Generation ++
- Relevance to large-scale optimization??

<u>Case study 1</u>
Optimizing emergency responses: developing operations research tools for Flood response in Bangladesh

Problem Statement

- How we can maximize the coverage of shelter points given:
  - Disrupted road network
  - Resource constraints
  - Limited capacity of vehicles

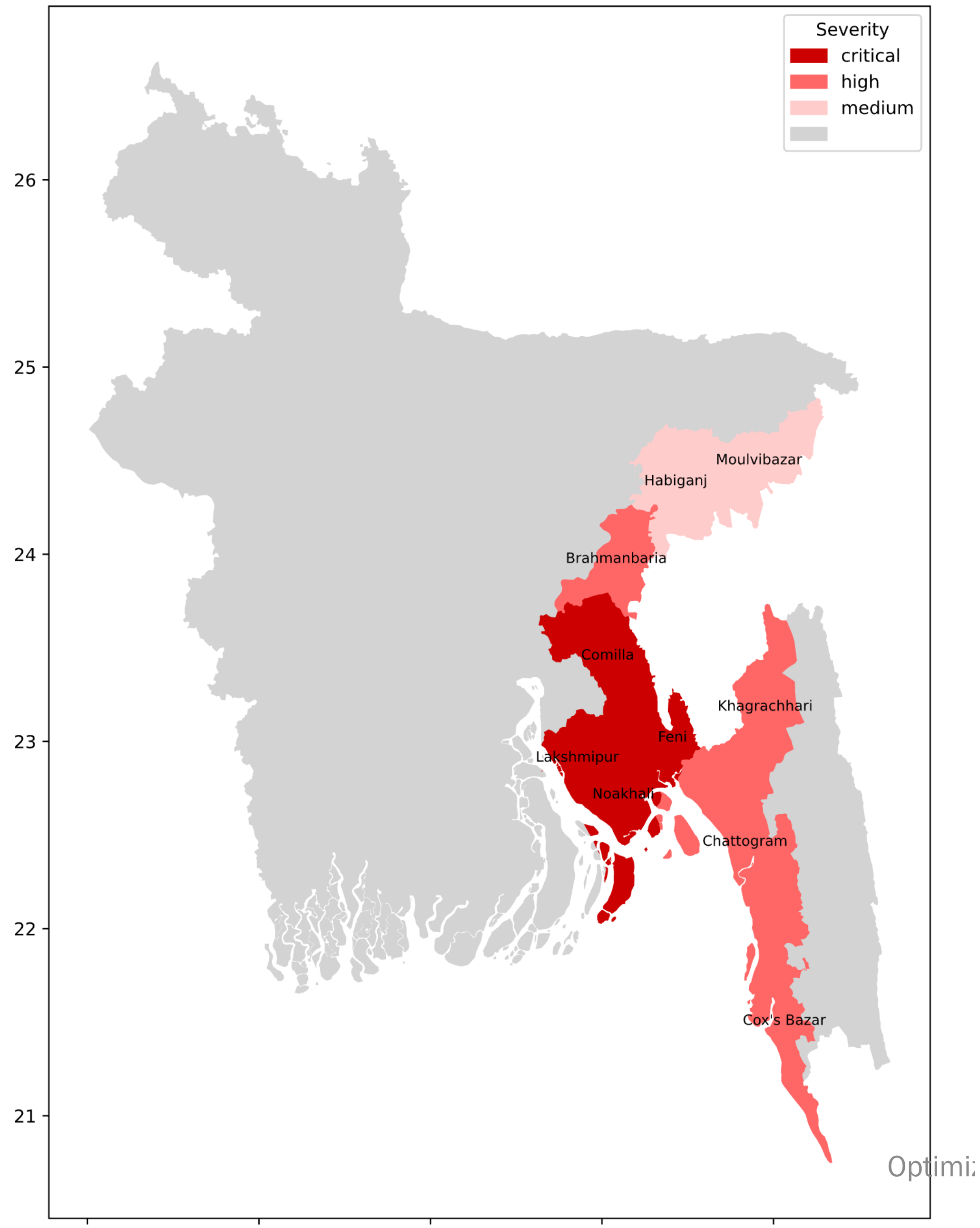
- Coverage: delivering reliefs from warehouse to shelters

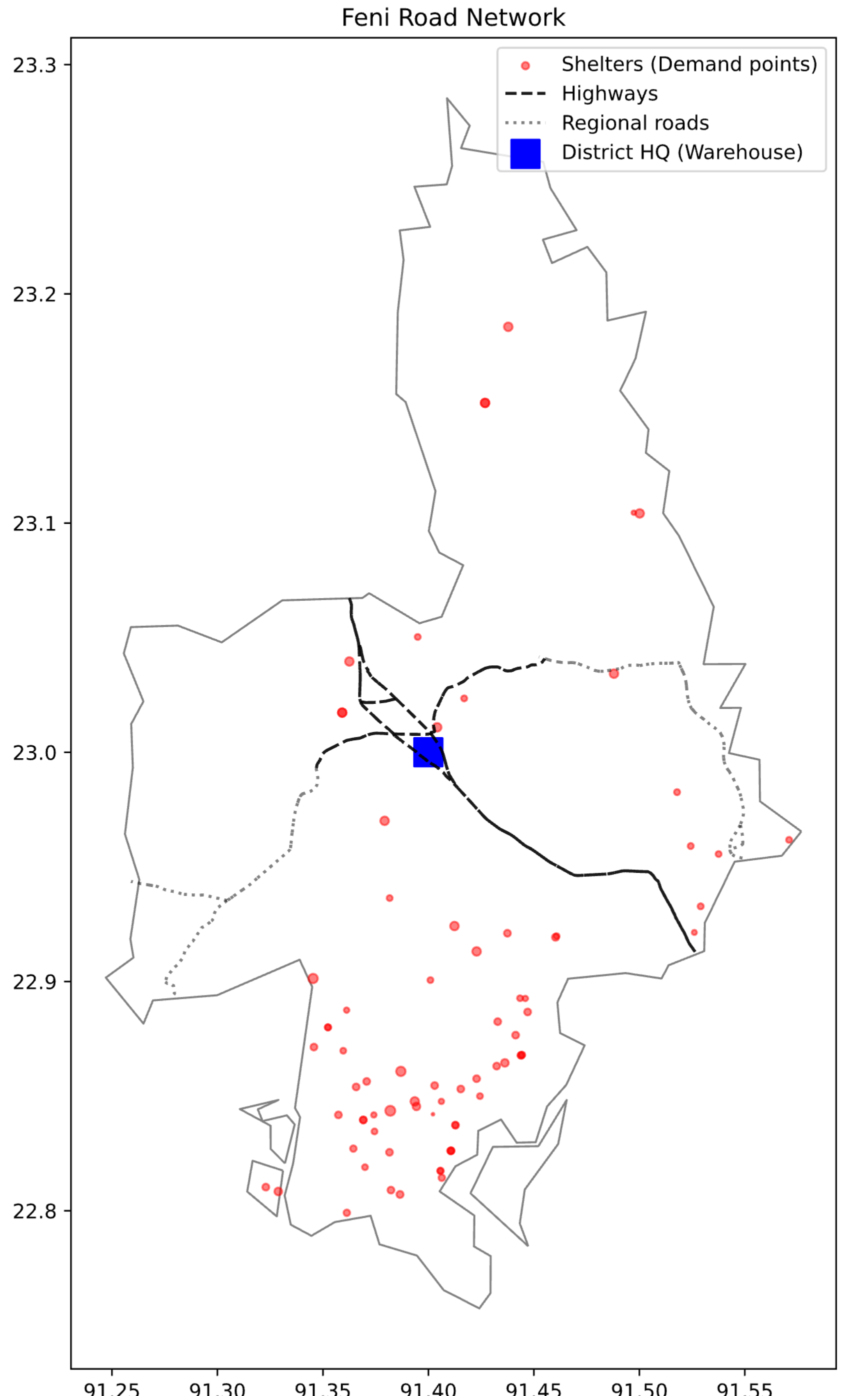
Data

- Cyclone shelter centers geolocation
- Road networks in Bangladesh
- GIS map of each districts
- Population in each district

- **Warehouse:** need to assume
- **Shelters:** capacity, geo-location
- **Road network:** national& regional highway, other roads, disrupted (can we get flood elevation or other info++ Riad)
- **Demand:** resource needed, Location of people
- **Resource/relief:** Quantity and warehouse location

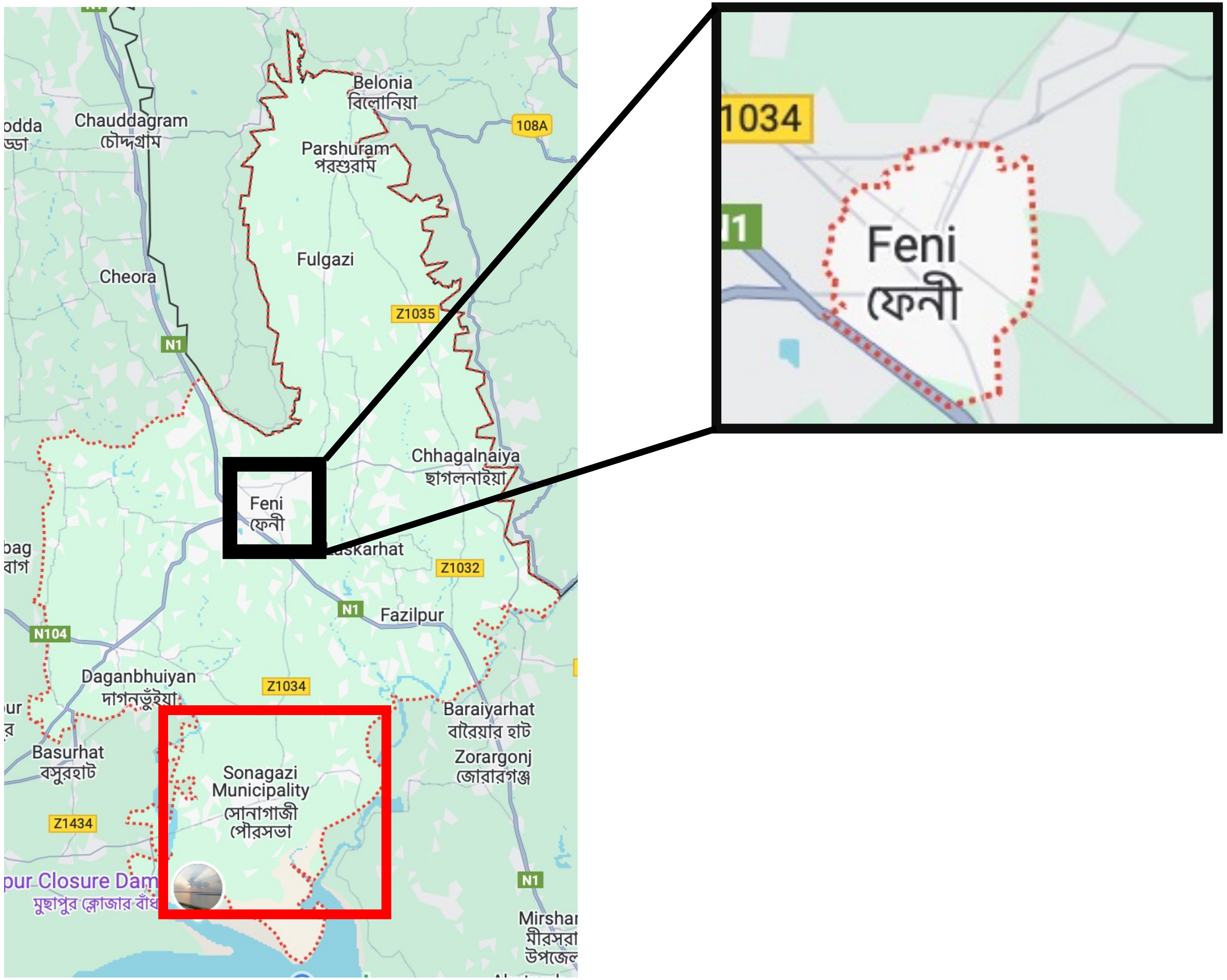
Data Exploration





Feni

- Total population in Feni 1.6M
- Sonagachi (where most shelters are) 0.39M population
- 0.6M in Feni Sadar (small central region)



Optimization model (VRP's variant)

<u>Conceptual Model</u>

1. Objective: **maximizing coverage** of shelter (demand) points
2. DV: no. of vehicles (# of drone, helicopter, truck), capacity of these vehicle
   a. Vehicle level: x_ijk, from where to where
   b. Routing level: road selection (disrupted, non-disrupted routes)
3. Input parameters: packages.
   a. Disrupted vs non-disrupted networks
4. Constraint
   a. Travel each demand points only once
   b. Capacity constraints: for each vehicle
   c. Travelling distance: helicopter (max coverage), every vehicle (truck refuel), other practical limits
   d. Time-window

- Capacity Consideration:
  - The decision variables are multiplied by the truck and drone capacities, ensuring that the total amount of supplies delivered does not exceed the availability at each warehouse.
- Availability Constraint:
  - The constraint ensures that the total resources delivered from each warehouse, by trucks and drones combined, do not exceed the available resources at that warehouse.

Math Programming

Results

Web app

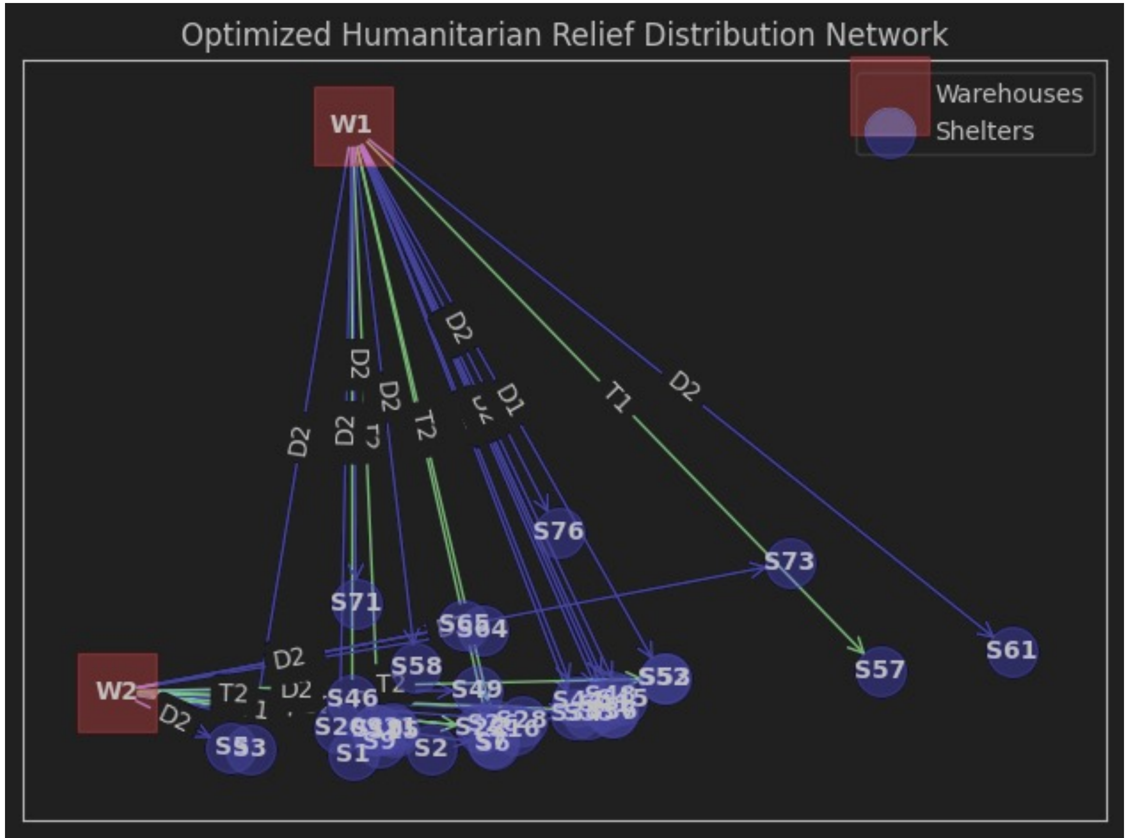
- Input
  - Availability (in warehouse) and capacity (of vehicles)
- Output
  - A table
  - A GIS map

Reference data

- 25% coverage
  availability = {'W1': 1500, 'W2': 2000}
  capacities = {'D1': 1000, 'D2': 2000, 'T1': 1600, 'T2': 2000}
- 46% coverage
  availability = {'W1': 1500, 'W2': 20000}
  capacities = {'D1': 1000, 'D2': 12000, 'T1': 1600, 'T2': 2000}

Main Task for now:

1. Build the minimalistic online web app (anyone can input these two inputs, and get the GIS map)
2. Edges of the map should be roads of GIS graph, not straight line, add an animation if possible



Computational Result: Dataset

- Dataset 1 (Wu et al., 2024):

- Dataset 2 (US Arctic emergency response related VRP): summary of the dataset+

Implementation

- Modeling: Python/Pyomo
- Solver: CPLEX/Gurobi
- Simulation: AnyLogic
- Versioning: Github
- Packaging: Docker & Streamlit