A DES model for fire service operation

Ali Pirmohammadi

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Introduction and Motivation

Emergency facility location problem has been broadly studied throughout literature.

There are many source of uncertainties involved in problem, for example:

1. Uncertainty in **demand** (Time and Location)
2. Uncertainty about network situation and unknown **travel time**
3. So called **'Congestion'** Problem.

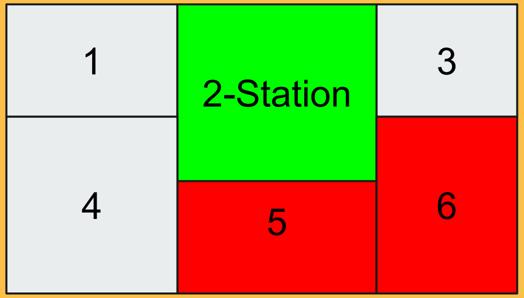
The proposed DES model aims to **address the uncertainties** and **consider the congestion problem** in emergency facility problem by :

1. It provide decision makers with a **handy tool** to accurately **evaluate decisions** for improvement and to **assess the system's performance** as well.
2. It can be **used alongside an optimization model** to better address the complex location problem

Emergency Facility Location Problem

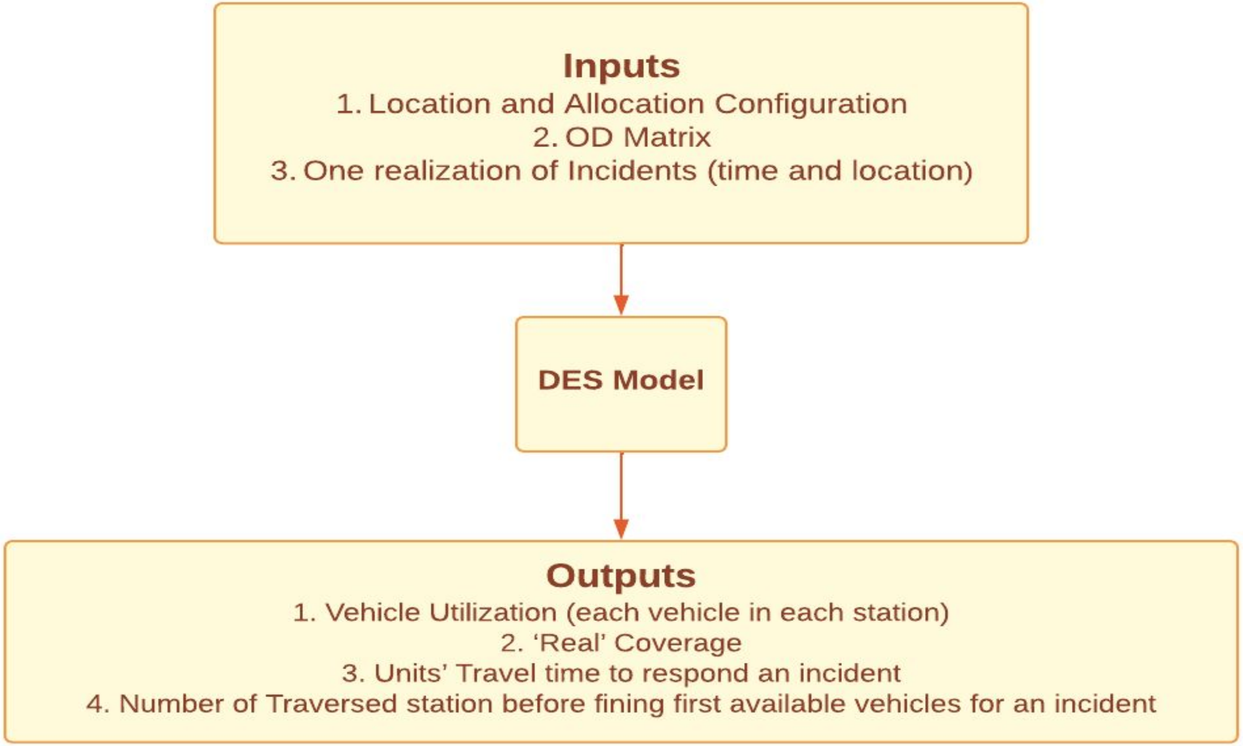
1. Units must get to every incidents within standard time.
2. Planners aims to locate station and allocate vehicles as to:
   - Maximize the coverage (within standard time) - Maximum Covering Problem
   - Minimize the travel time between station and incidents - P Median Problem
3. We might want to focus on standard time in planning phase but at the end of the day **every** incidents must be responded in operation.
4. The problem is considered '**Strategic Problems**' and due to the enormous costs involved, it is studied as **static problem**.

Congestion Problem

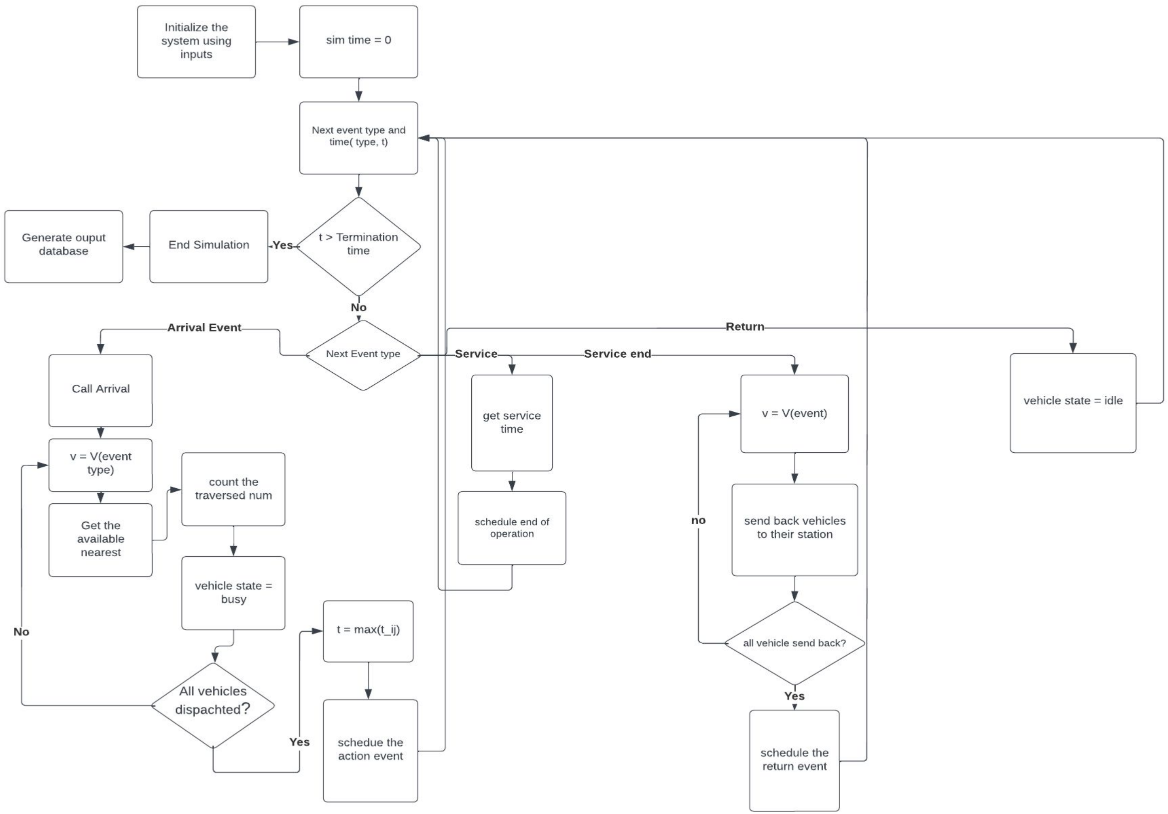


The DES Model

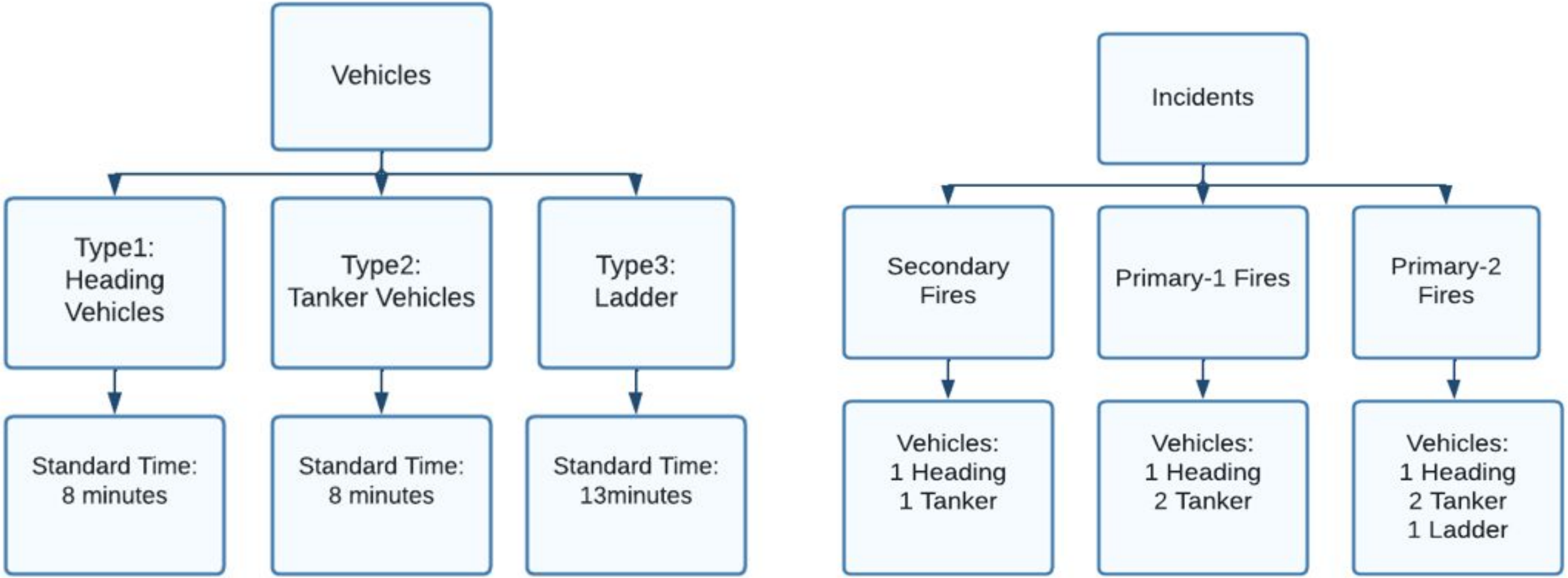
Overview



The DES Model Flow Chart



Assumptions



Notes

Behind the Scenes

1. The Simulation program is implemented using **Python**.
2. The program uses **OOP** capability to implement the logic in a clear way.
3. The processes are handled through **asynchronous programming** thanks to the **Simpy** package.
4. A single run of the simulation consisted more than **300 vehicles** dispatched to **30000 event** over a period of one year, which took about **96 seconds** to execute using a single core of an **Intel Core i7-5550U (5th Gen)** with **8 GB of RAM**.
5. It is assumed that **cooperative operation** are allowed, which means it is not necessary that all the needed units dispatched from a same station. The central department search through nearest available vehicles to send to the incident.
6. The model is validated on a 10*10 network with 50, 100 incidents.

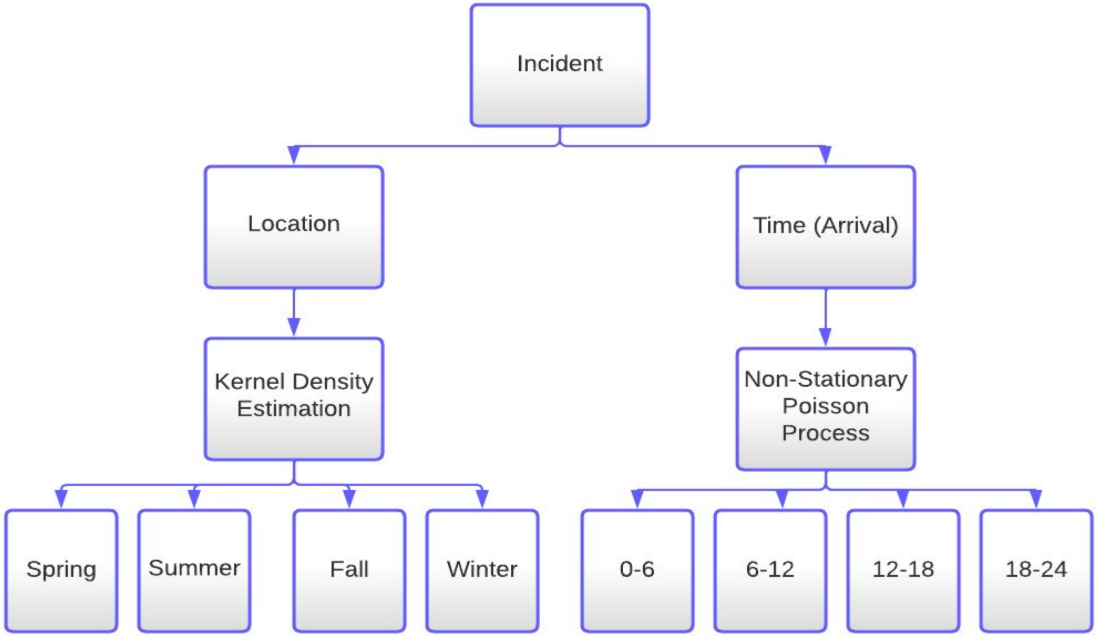
Case Study
Tehran

1. Annually about **30000** fire incidents occur in Tehran.
2. Fire Department has **125 station**. Each station has **1 heading** vehicles and **2 tanker** as well.
3. Fire department also has **33 ladder** which are located in main station.
4. On average, annually there were **20000 secondary fires** and **8000 primary-1 fires** and **2000 primary-2 fires** in recent years.

Case Study
Experiment

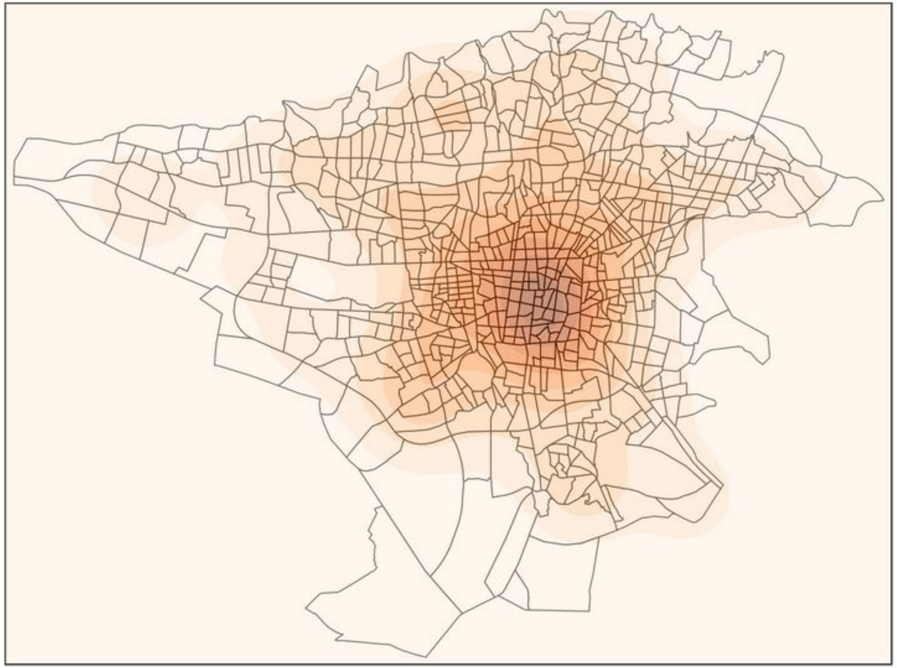
1. In the following experiment the DES model is used as tool to compare performance of different resource configuration.
2. 3 configuration are used :
   - Current resource configuration
   - Solution of Optimization Model (Nominal model)
   - Solution of Optimization Model (MiniGap model)
3. The experiment for each configuration runs 15 times:
   - 5 different demand scenarios
   - 3 different travel times (Am-Peak, Pm-Peak, Off-Peak)
4. Demand scenarios are sampled using proposed method.
5. The current database is not used as demand realization because it contain lots of errors; on the other hand, lots of scenarios can be created using proposed sampling method.

Case Study
Modeling Arrival– Overview

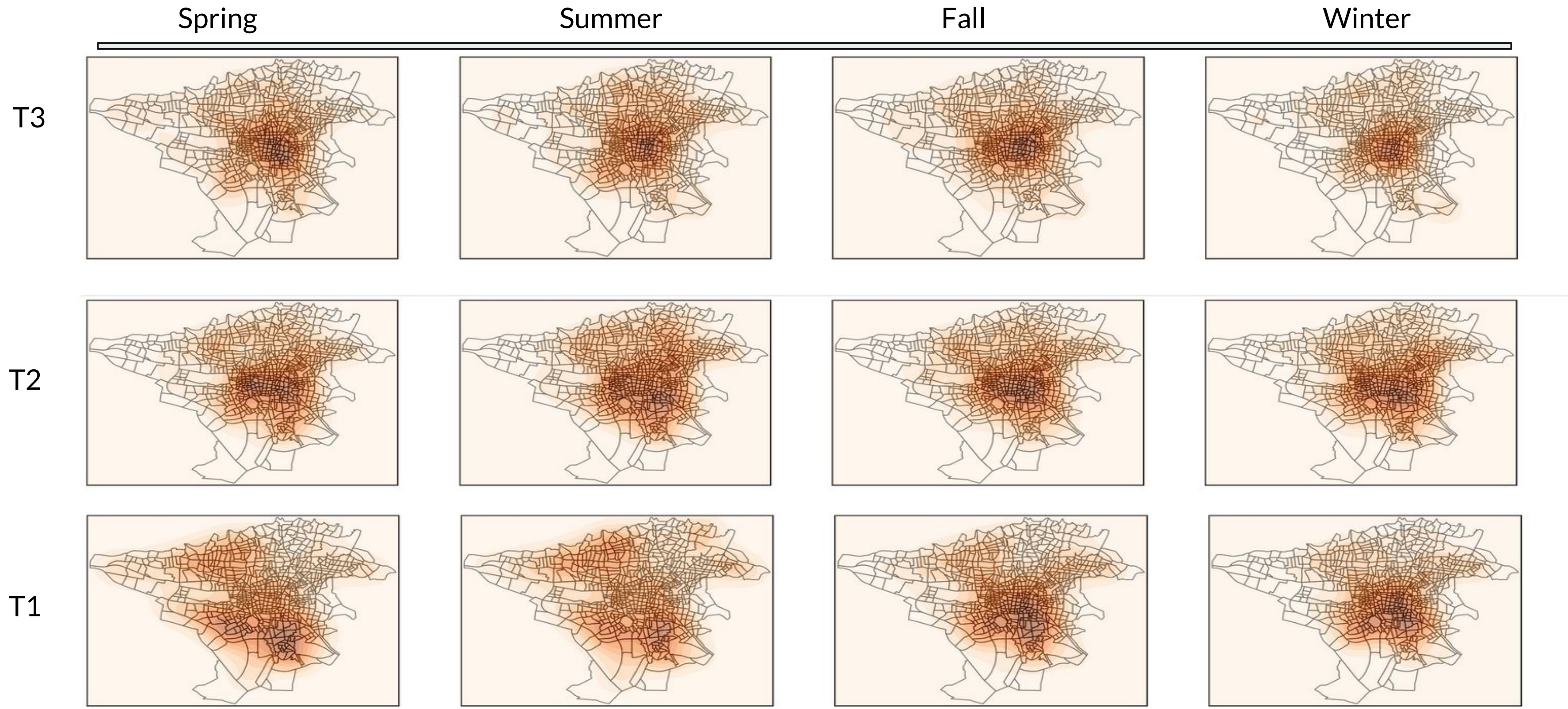


Case Study
Modeling Arrival - Location

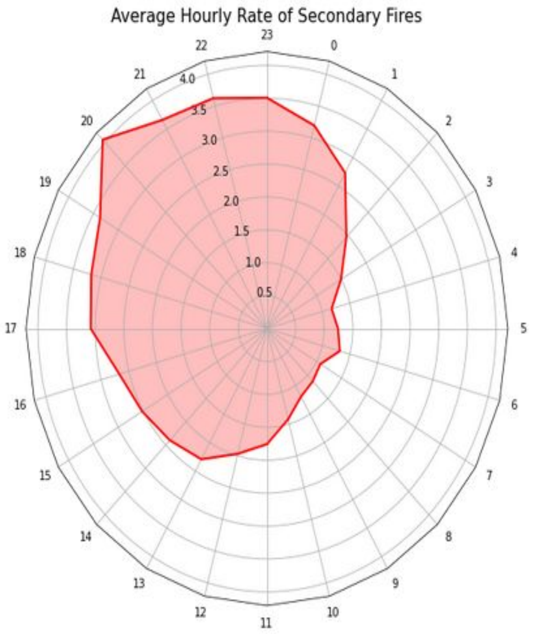
$$\widehat{f}_h(x) = \frac{1}{n}\sum_{i=1}^{n} K_h(x - x_i) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right),$$

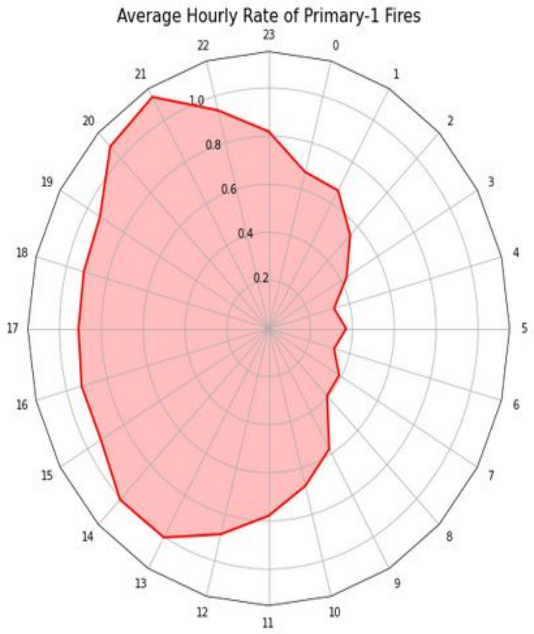


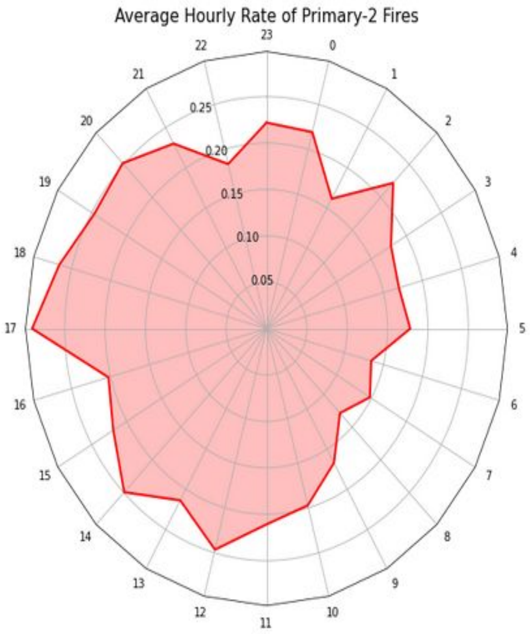
Case Study
Modeling Arrival - Location



Case Study
Modeling Arrival - Time







Case Study
Optimization Model

TEAM: Maximize $Z = \sum_{i \in I} a_i y_i$

s.t.

$$\sum_{j \in N_i^p} x_j^p \geqq y_i, \quad \text{for all} \quad i \in I$$

$$\sum_{j \in N_i^s} x_j^s \geqq y_i, \quad \text{for all} \quad i \in I$$

$$\sum_{j \in J} x_j^p = p^p$$

$$\sum_{j \in J} x_j^s = p^s$$

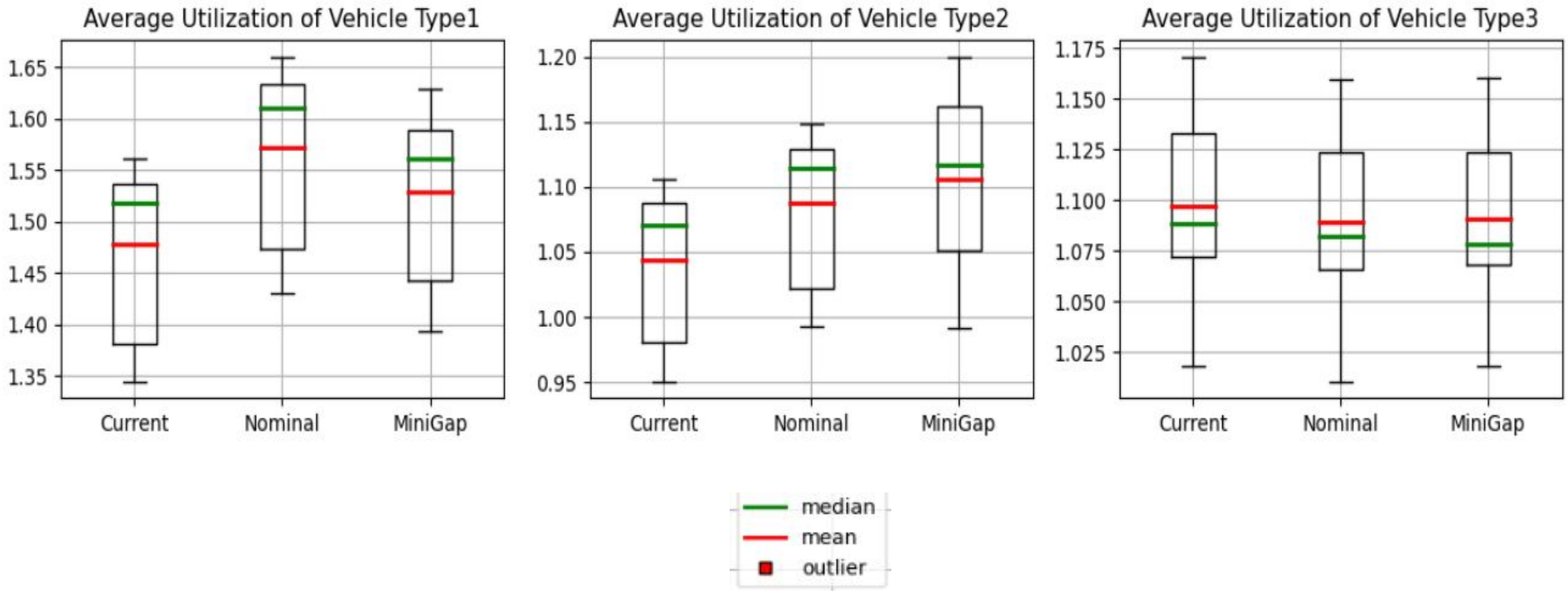
$$x_j^s \leqq x_j^p, \quad \text{for all} \quad j \in J$$

$$x_j^s, x_j^p = 0, 1, \quad \text{for all} \quad j \in J$$

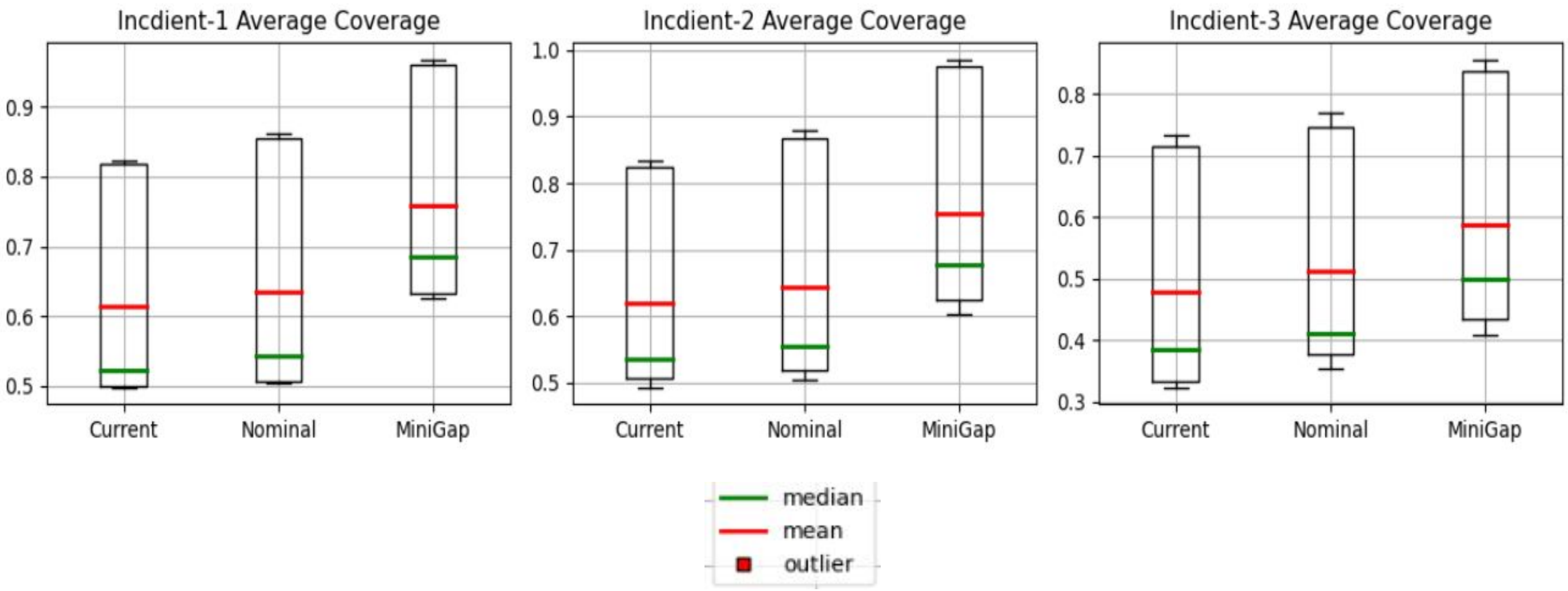
$$y_i = 0, 1, \quad \text{for all} \quad i \in I$$

$$MiniGap : Maximize\ X = \sum_{s,i} (a_{is} y_{is} - a_{is}^* y_{is}^*)$$

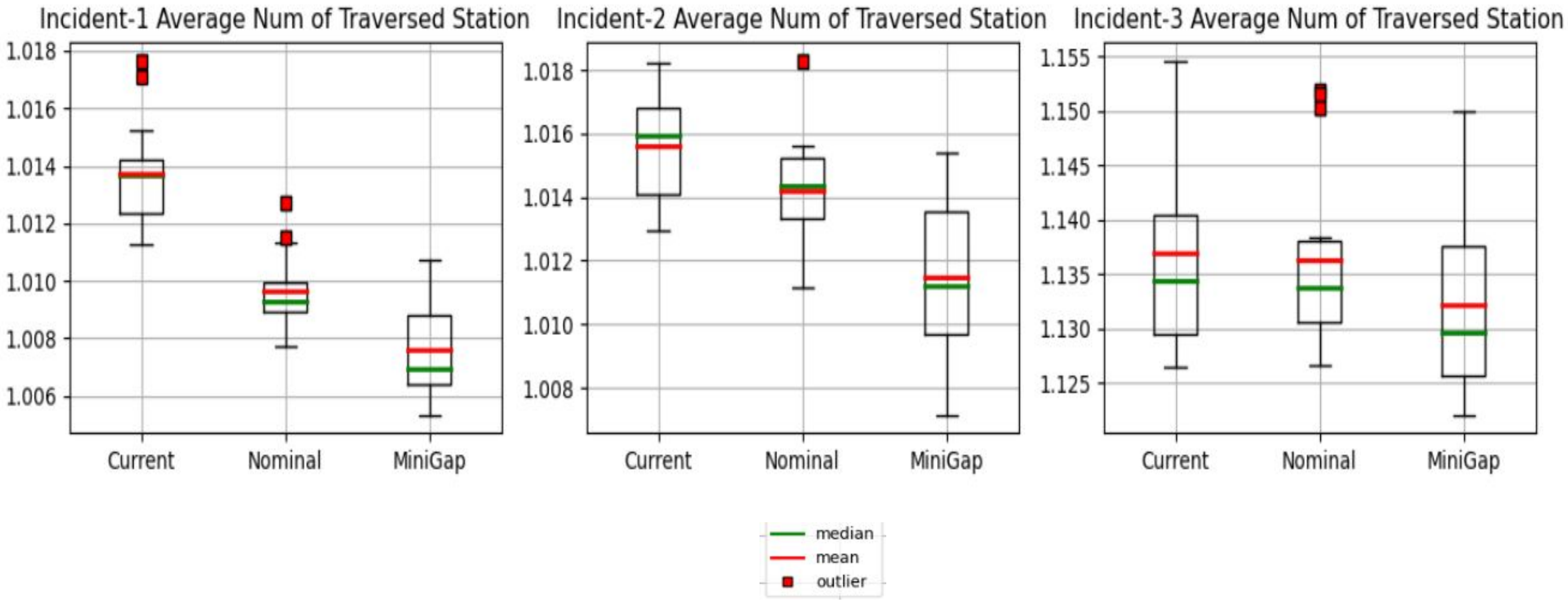
Case Study
Results-Utilization



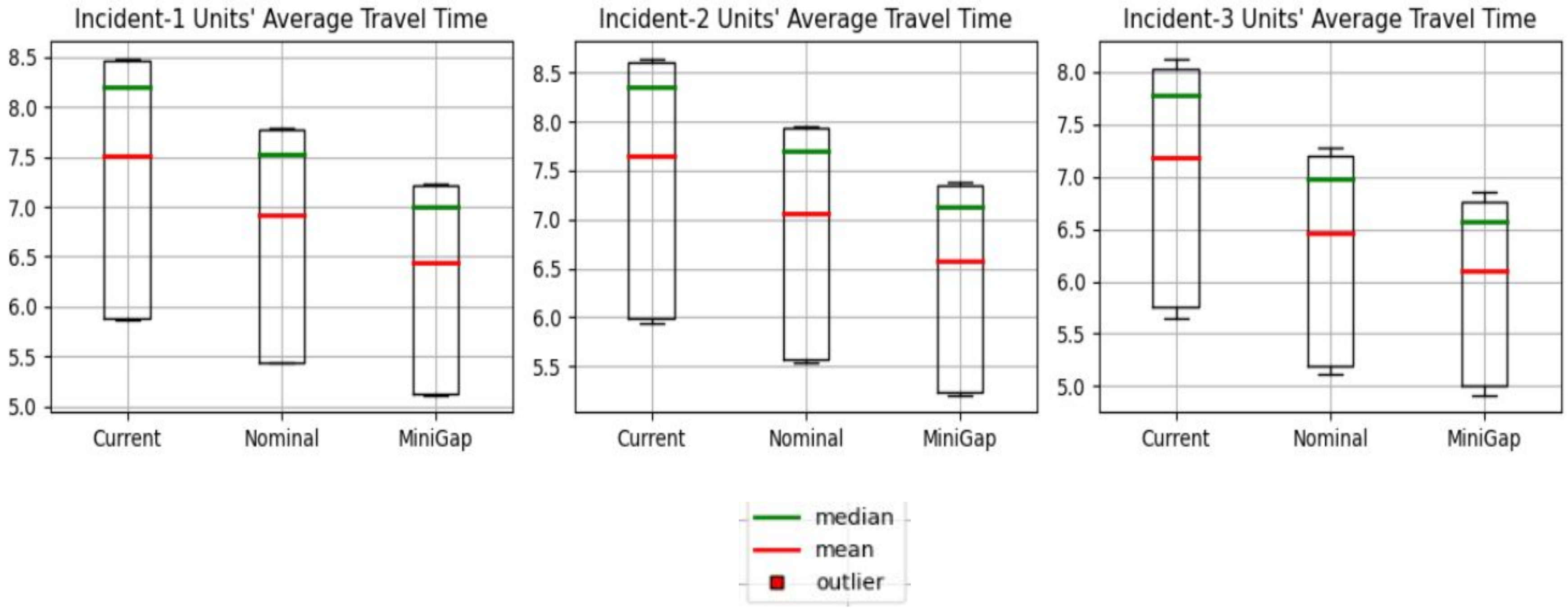
Case Study
Results-Coverage



Case Study
Results-Number of Traversed Station

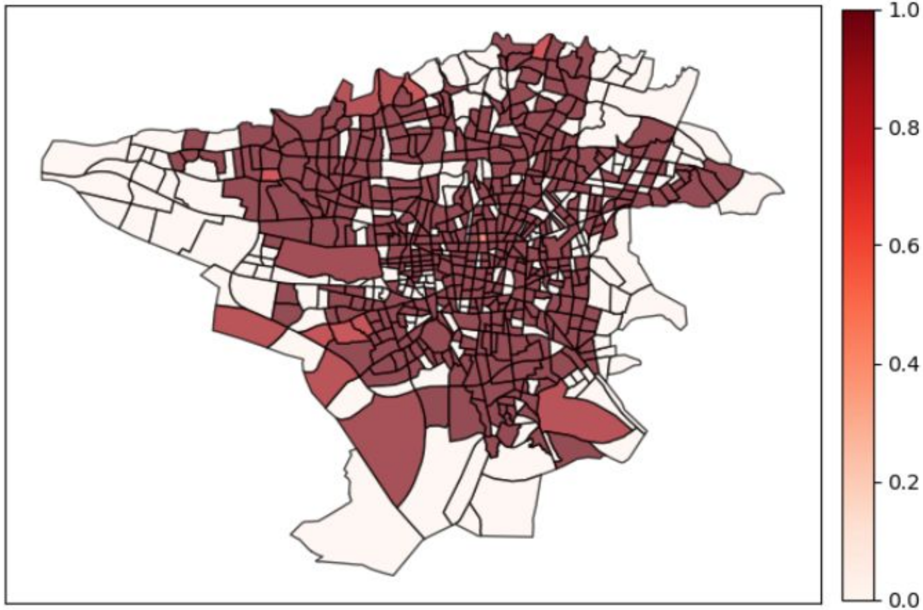


Case Study
Results-Travel Time

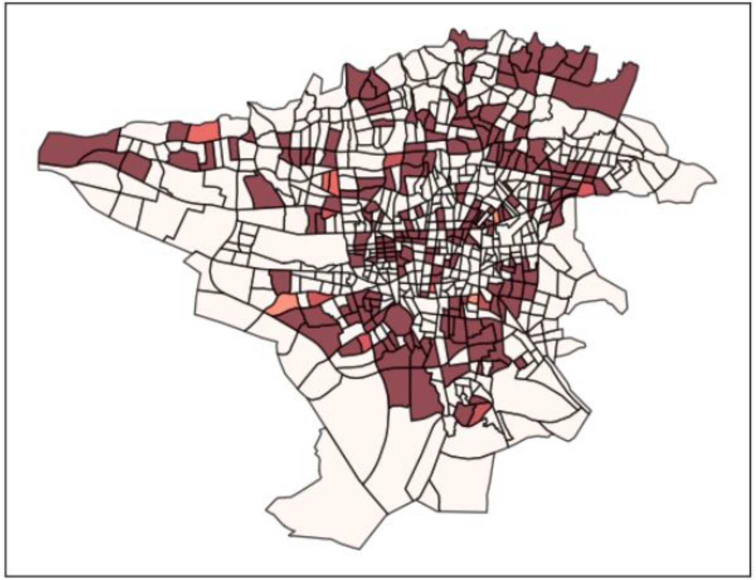


Case Study
Results-Zonal Results (Primary-3 Coverage)

MiniGap

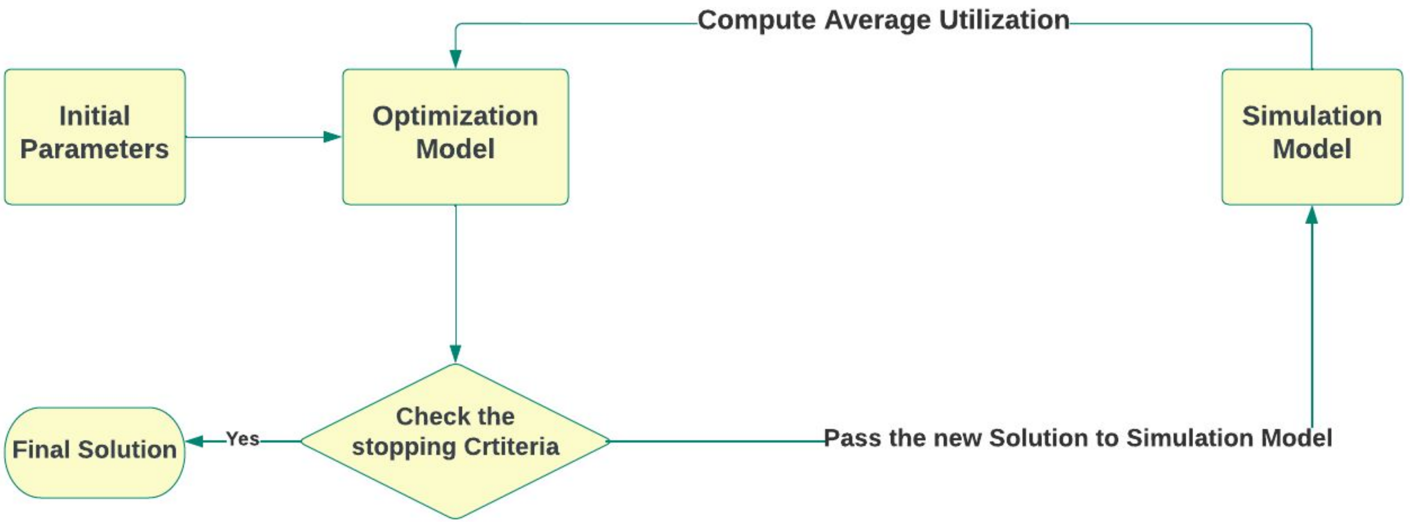


Current



Simulation-Optimization Approach
Expected Coverage

$$\text{Maximize} \sum_{k=1}^{N} \sum_{j=1}^{M} (1-p)\, p^{j-1} h_k y_{jk} = \sum_k \sum_j w_j h_k y_{jk}$$



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3. Charles ReVelle, Kathleen Hogan, (1989) The Maximum Availability Location Problem. Transportation Science 23(3):192-200.
4. Mark S. Daskin, (1983) A Maximum Expected Covering Location Model: Formulation, Properties and Heuristic Solution. Transportation Science 17(1):48-70.

Thanks !