# SCM.293 Urban Last-Mile Logistics

# Assignment II:

# The Two-echelon Location-Routing Problem

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*Assigned on Thursday, April 21, 2022.*

*Due electronically via course site on Tuesday, May 3, 2022, 23:59 pm EST.*

*Assignment is to be completed individually, no group-work.*

## 1. Introduction

You are analyzing the last mile delivery operations of a CPC company who serves the daily demand of its customers in Manhattan. The company wants to optimize its distribution network to minimize costs of operations. They can deploy hubs and satellite facilities (SFs) and deploy different vehicles on the first and second echelon. In this assignment, we ask you to implement a mixed integer linear programming model using Gurobi to design a two-echelon distribution network that minimizes their total costs of operations. In the following, we first describe the data for the assignment and the required deliverable. We then provide assignment instructions. Finally, we provide a number of assignment notes that should help you with the building of the model.

## 2. Data

On the course site you will find several data sets described in the following.

`2022_SCM293_assignment2_NYC.csv`: a demand data set containing all relevant information for customers in Manhattan:

- `Customer ID`
- `Customer location`

- `Delivery zipcode`
- `Order size (in units)`

`2022_SCM293_depots_NYC.csv`: a data set containing all relevant information for candidate depot locations:

- `Depot ID`
- `Depot type (hub or SF)`
- `Depot location`
- `Depot capacity`
- `Depot fixed cost`

`2022_SCM293_assignment2_2ndE_vehtypes.csv`: a dataset containing all relevant base case parameters for the second echelon vehicle types that you are going to include in your analyses:

- `Carrying capacity in units`
- `Fixed cost per route`
- `Distance cost per km`
- `Hourly cost while on route`
- `Inter-stop speed in km/hour`
- `Line-haul speed in km/hour`
- `Service time per stop`
- `Route setup time per stop`

`2022_SCM293_assignment2_1stE_vehicles.csv`: a dataset containing all relevant base case parameters for the first echelon vehicles that you are going to include in your analyses:

- `Vehicle type`
- `Carrying capacity in units`
- `Fixed cost per route`
- `Distance cost per km`

Moreover, you will find a basic code structure which should serve as a starting point for your implementation: `Assignment I - 2E-LRP in NYC - starter.ipynb`. When Running the first cell in section ”Project Zipcode Centroids and Depot Nodes on OSM Road Network and Plot”, you should be able to visualize the image represented on Figure 1.

**Figure 1** **Zipcodes and depots**

## 3. Deliverables

Please work on this assignment individually. Please hand in before the submission deadline:

- An executable iPython notebook with your model implementation
- A quick Word / PDF write-up summarizing the answers to the following questions based on the results you obtained from your model

## 4. Assignment instructions

The assignment is composed of three parts described bellow.

### 4.1. Part 1: "Pure-play" two-echelon distribution network (50 points)

The company wishes to design its distribution network for serving its facilities in Manhattan. They wish to put in place a "pure-play" two-echelon network, where hubs send freight to SFs and SFs to customers. The company can open one or several hubs out of a set of potential candidates. The company can open one or several SFs out of a set of potential candidates. Both hubs and SFs have capacity limitations. A fleet of maximum 20 echelon vehicles can be employed to perform inter-facility routes between hubs and SFs. Several SFs can be served on a single first-echelon route. One SF can be served by multiple first-echelon route. Last-mile distribution can be performed from SFs only. Two different types of vehicles can be employed for last mile distribution: vans and bikes.

Implement a mixed integer linear programming model using Gurobi to design a two-echelon distribution network that minimizes the total costs of operations:

- `Fixed facility cost of hubs`
- `Fixed facility cost of SFs`
- `Cost of first echelon transportation (fixed vehicle cost and routing cost)`
- `Cost of second echelon transportation (fixed vehicle cost and routing cost)`

Furthermore, please determine the following metrics after your optimization:

- `Number of hubs activated`
- `Number of satellite facilities activated`
- `Number of first echelon vehicles employed`
- `Total customer demand (parcels) served through vans`
- `Total customer demand (parcels) served through bikes`
- `Total customer demand (parcels) served through hubs`
- `Total customer demand (parcels) served through SFs`
- `Fixed facility cost of hubs`

- `Fixed facility cost of SFs`
- `Cost of first echelon transportation (fixed vehicle cost and routing cost)`
- `Cost of second echelon transportation (fixed vehicle cost and routing cost)`

*Note: Please set the Gurobi numerical solver to terminate once an optimality gap of 0.25% is reached*

### 4.2. Part 2: Mixed two-echelon network (30 points)

The company considers deploying its last-mile distribution routes from both hubs and SFs. Design a two-echelon distribution network that minimizes the costs of operations (as previously). Adapt the formulation to account for the fact that last-mile distribution can be performed from both SFs and hubs. Consider that last-mile distribution from the hub can be performed using last-mile distribution vehicles, i.e., vans and bikes. When applying capacity constraints to the hubs, consider all outgoing parcels (i.e., transferred towards the SFs or distributed from the hub)

Compare the key performance indicators of the mixed two-echelon network with a previous solution. Briefly discuss your results.

*Note: Please set the Gurobi numerical solver to terminate once an optimality gap of 0.25% is reached*

### 4.3. Part 3: Limited service time (20 points)

The service time to perform deliveries has dropped from 10 hours to 5 hours for all vehicle types. Which type of network design minimizes the costs – the "pure-play" or mixed two-echelon network? Briefly discuss your results.

*Note: Please set the Gurobi numerical solver to terminate once an optimality gap of 0.25% is reached*

## 5. Assignment notes

### 5.1. Recommended Reading

For this assignment, we recommend the following reading, which you can find on the course site: *Boccia, M., Crainic, T. G., Sforza, A., Sterle, C. (2011). Location-routing models for designing a two-echelon freight distribution system. Technical report, CIRRELT, Université de Montréal, 91*

### 5.2. Initial formulation

Use as a starting point the two-echelon routing problem formulation presented in class and based on the recommended reading. We have used the three-index formulation (section 4.2 or the paper).

This formulation utilizes explicit vehicle routing on two echelons. This means that:

- Decision variables relevant to routing (i.e., $x_{ij}^v$, $r_{ij}^t$) and fleet size (i.e., $u_i$) are defined at both echelons
- The objective function considers decision variables relevant to routing at both echelons (i.e., including the values of $x_{ij}^v$)
- The objective function considers decision variables relevant to routing at both echelons (i.e., including the values of $x_{ij}^v$)
- Model constraints considers routing decisions at both echelons (e.g., Constraints (2) to (9) in Boccia et al. (2011))

Note that several errors have been found in the formulation by Boccia et al. (2011). These have been corrected in the formulation presented in the class:

- In constraints (4), $i, j \in Z \cup S$ should be $i, j \in Z$
- In constraints (8), $i, j \in S \cup P$ should be $i, j \in S$
- In constraints (16), $k^v$ should be $k^t$
- In constraints (18), $u^t$ should be $u_t$
- In constraints (13), $\sum\limits_{s \in S} f_{ps}$ should be $\sum\limits_{s \in S} \sum\limits_{t \in T} f_{ps}^t$

### 5.3. Required adaptations

The data set that you will use for the assignment is composed of over thousand customers. Therefore, explicit routing on two echelons is intractable. We ask you maintain routing decisions on the first echelon (i.e., explicit routing of vehicles performing transportation between hubs / platforms and satellite facilities). Given the large-scale nature of the problem, we ask you to make two adaptations to the formulation described in the following.

*Adaptation 1: Continuum approximation methods for estimating the routing cost at the second echelon* . To incorporate continuum approximation for the second echelon routing, the following adjustments should be made:

- Adjust the decision variables at second echelon (e.g., no longer consider explicit routing variable $x_{ij}^v$
- Adjust the objective function (e.g., no longer consider the cost of each arc travelled or vehicle, but rather consider an estimation of the route cost based on continuum approximation methods)

- Adjust the constraints (e.g., no longer consider constraints using explicit routing variables at the first echelon, such as the subtour elimination)

*Adaptation 2: Consider that one SF can be served by multiple vehicles* Constraints (6) should be slightly adapted to account for the large-scale nature of the problem. In their current form, they imply that every active satellite must be served through a single route, which in turn implies that the demand at each satellite (i.e., customer demand allocated to the satellite) is lower or equal to the capacity of first echelon vehicles. In a large-scale setting, the demand at each satellite might be larger than the capacity of first echelon vehicles. This implies that several vehicles might be required to serve a satellite facility and that this constraint is no longer valid or needed. However, while removing this constraint will still yield feasible solutions, it might also lead to first-echelon routes visiting inactive satellite facilities. You should therefore *adapt* this constraint to ensure that first echelon routes are only visiting active satellites.

### 5.4. Other notes

Please note the following:

- An alternative formulation for subtour elimination constraints (4) and (8) in Boccia et al. (2011) can be found in the single echelon location-routing problem presented in class based on Wu et al. (2002). You can use any of these two formulations.
- Make sure that you account for the fact that distances returned by OSMNx server are in meters.