**Instructions:**

We will practice modeling a transportation problem and a facility assignment problem in this lab. These problems can be formulated as appropriate optimization problems with an associated objective function and constraints. Two-dimensional decision variables are useful in these problems, and we will focus on using such two-dimensional variables in model building using `pyomo`.

We will continue to model problems by loading information from files in this lab. We will also continue modeling problems with integer variables, wherever required.

Recall, to load directly from a file with comma separated values (`.csv` file), we used `pandas` library. The construct `pandas.read_csv` helps to read contents from a `.csv` file. Please check https://pandas.pydata.org/pandas-docs/stable/getting_started/index.html to know more about `pandas` library.

In this lab, accessing the data frame using `iloc` is discussed in detail. For more details on this `iloc` function, please see https://pandas.pydata.org/pandas-docs/stable/reference/api/pandas.DataFrame.iloc.html

Please follow the instructions given below:

- Please use different notebooks for solving different problems.
- The notebook name for Exercise 1 should be `YOURROLLNUMBER_IE507_Lab5_Ex1.ipynb`.
- Similarly, the notebook name for Exercise 2 should be `YOURROLLNUMBER_IE507_Lab5_Ex2.ipynb`.
- Please post your doubts in MS Teams or Moodle so that TAs can clarify.

For more details on pyomo, please consult https://pyomo.readthedocs.io/en/stable/index.html.

There are only 2 exercises in this lab. Try to solve all problems on your own. If you have difficulties, ask the Instructors or TAs.

Only the questions marked [**R**] need to be answered in the notebook. You can either print the answers using `print` command in your code or you can write the text in a separate text tab. To add text in your notebook, click `+Text`. Some questions require you to provide proper explanations; for such questions, write proper explanations in a text tab.

After completing this lab's exercises, click File → Download .ipynb and save your files to your local laptop/desktop. Create a folder with name `YOURROLLNUMBER_IE507_Lab5` and copy your `.ipynb` files to the folder. Also copy the `.csv` files to the folder. Then zip the folder to create `YOURROLLNUMBER_IE507_Lab5.zip`. Then upload only the `.zip` file to Moodle.

The deadline for today's lab submission is **tomorrow, $17^{th}$ September 2020, 11 59 PM Indian Standard Time (IST)**.

**Exercise 1: Transportation Problem [15 marks]**
A customer has contacted Jai Logistics for transporting air-conditioner units (ACUs) from warehouses to markets. There are eight warehouses, each of which has some truck-loads of ACUs in stock. These ACUs must be transported to eight markets for satisfying the demand. You are interning at Jai Logistics and you are given the task of finding out how many ACUs must be transported from each warehouse to each market.

1. **[R]** Let $C[w, m]$ be the cost of transporting one truck-load of ACUs from $w$ to $m$. Write a general optimization problem to minimize the total transportation cost. Use appropriate notations and define appropriate sets to be used in the optimization problem.

2. Use the costs, demands and available stocks from Table 1 to create a `.csv` file, similar to that used in the practice exercise. You can use the `transport.txt` file uploaded in Moodle to create the `.csv` file. Name the file as `lab5_ex1.csv`. Use simple and appropriate names for the headers.

3. Copy the file to colab environment.

4. Use `pandas` to load the `.csv` file contents.

5. Create a model using `pyomo` to solve your optimization problem. Use the loaded contents of `.csv` file to create your model. Use `iloc` function of `pandas` library to access the data frame contents obtained from the `.csv` file.

6. Use `cbc` solver to solve your optimization problem. In your code, remember to specify which variables are integers.

Table 1: Cost of Transporting a Truck-load of AC Units

| | Markets | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Warehouses | Indore | Jodhpur | Vellore | Kanpur | Hyderabad | Patna | Raipur | Cuttack | **Avail. Stock** |
| Ahmedabad | 427 | 617 | 1270 | 982 | 915 | 943 | 974 | 1265 | 100 |
| Bengaluru | 1179 | 1623 | 372 | 2072 | 257 | 1373 | 1052 | 959 | 250 |
| Chennai | 1409 | 1823 | 59 | 2127 | 358 | 1422 | 1304 | 811 | 200 |
| Delhi | 1123 | 533 | 2265 | 467 | 1896 | 941 | 1232 | 1348 | 200 |
| Kolkata | 1712 | 2079 | 1830 | 1499 | 1929 | 439 | 691 | 128 | 150 |
| Lucknow | 886 | 760 | 1965 | 83 | 1759 | 395 | 795 | 1332 | 90 |
| Mumbai | 546 | 817 | 1045 | 1232 | 905 | 1211 | 1187 | 1487 | 290 |
| Nagpur | 495 | 1062 | 1113 | 1121 | 802 | 1125 | 474 | 801 | 200 |
| **Demand** | 75 | 300 | 250 | 200 | 400 | 100 | 50 | 70 | |

7. **[R]** Report the number of truck-loads of ACUs that are transported (report only those values that are nonzero) from warehouses to markets. Report the total cost also.

8. **[R]** Suppose the Bengaluru-Patna link is disrupted and no transportation is possible on the link. Without changing the pyomo model, how will you solve this problem? You are only allowed to change the `.csv` file.

9. **[R]** Report the new solution value and the nonzero flows in the network.

**Exercise 2: Assigning Locations [20 Marks]**
Mansarov Constructions Inc. has to build $n \in \mathbb{N}$ different types of factories, one at each of the $n$ locations. The cost of constructing (setup cost) the $i^{th}$ facility at the $j^{th}$ location provided in the Table 2 below. Mansarov Constructions Inc. wants to minimize the sum of the costs of assigning all the facilities to the locations.

| Factory | Location | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 1 | 19 | 12 | 18 | 19 | 22 | 21 | 17 | 20 | 16 | 15 | 21 | 24 |
| 2 | 22 | 22 | 19 | 21 | 22 | 24 | 18 | 17 | 21 | 19 | 22 | 23 |
| 3 | 18 | 23 | 20 | 20 | 21 | 22 | 19 | 18 | 20 | 23 | 19 | 19 |
| 4 | 18 | 21 | 20 | 18 | 17 | 19 | 24 | 16 | 18 | 16 | 20 | 24 |
| 5 | 23 | 17 | 16 | 19 | 24 | 21 | 23 | 21 | 20 | 21 | 22 | 21 |
| 6 | 23 | 20 | 17 | 16 | 20 | 23 | 22 | 25 | 24 | 19 | 17 | 20 |
| 7 | 22 | 18 | 17 | 15 | 22 | 24 | 23 | 20 | 22 | 19 | 23 | 20 |
| 8 | 24 | 22 | 21 | 23 | 18 | 17 | 16 | 19 | 24 | 21 | 20 | 23 |
| 9 | 21 | 20 | 17 | 18 | 16 | 24 | 19 | 17 | 18 | 20 | 21 | 23 |
| 10 | 19 | 22 | 21 | 24 | 20 | 23 | 19 | 18 | 23 | 24 | 25 | 20 |
| 11 | 20 | 24 | 22 | 20 | 23 | 19 | 18 | 16 | 22 | 24 | 21 | 24 |
| 12 | 22 | 23 | 24 | 20 | 21 | 20 | 20 | 19 | 17 | 19 | 20 | 22 |

Table 2: Set up cost of factories at different locations

1. [**R**] Write a mathematical model to solve the assignment problem explained above. Define all the variables and constraints clearly. Use appropriate notations and define appropriate sets to be used in your optimization problem.
2. Construct a `pyomo` model for this problem for a general $n$. You can assume that the cost matrix is given as data from a `txt` file and can be loaded as a `numpy` array.
3. Use the data in Table 2 to make a `.txt` file for your model. You can use the `setupcosts.txt` file uploaded in Moodle to create the `.txt` file. Name the file as `lab5_ex2.txt`.
4. Copy the file to colab environment.
5. Use `numpy.loadtxt` to load the data from `lab5_ex2.txt` file into a `numpy` array.
6. Adapt the general `pyomo` model you created, to use the data loaded from the `lab5_ex2.txt` file.
7. Use `cbc` solver to solve your optimization problem. In your code, remember to specify which variables are integers.
8. [**R**] Solve the problem and report which facility must be opened at each location.
9. [**R**] Now change the integer variables in your model to continuous variables, and re-solve the problem. Report the solution (only the non-zero values of the solution).
10. [**R**] Are the optimal costs for both problems same? Are the values of the variables still integer-valued? If yes, explain why.
11. Will the solution to the continuous problem become fractional (non-integer) if the costs are changed to non-integer values? Try changing the costs to different values and test whether the solution to the LP becomes fractional for any of them.

12. [**R**] Now suppose that, due to some reason, facility 1 cannot be assigned to location 4, facility 11 cannot be assigned to location 3 and facility 5 cannot be assigned to location 9. What changes in your `pyomo` model or in `lab5_ex2.txt` file will you make? Make these changes, and solve the integer problem and report the solution.