Instructions:

Try to solve all problems on your own. If you have difficulties, ask the instructor or TAs.

Please follow the instructions given below to prepare your solution notebooks:

- Please use different notebooks for solving different Exercise problems.
- The notebook name for Exercise 1 should be `ROLLNUMBER-labLL-ex1.ipynb`. `ROLLNUMBER-labLL-ex2.ipynb`, etc for others. 'LL' is the two digit lab number (lab-3 is 03, etc).
- Please ask your doubts to TAs or instructors or post in Moodle Discussion Forum channel.
- You should upload on the .ipynb files on Moodle (one per exercise).

Only the questions marked [**R**] need to be answered on paper. Write legible and to-the-point explanations. The work-sheet on which you write needs to be submitted before leaving the session.

Some other questions require plotting graphs (histograms, trajectories, level-sets etc) or tables. Please make sure that the plots are present in the submitted ipython notebooks.

Submission Time: Please check the submission deadline as show on the assignment web-page in Moodle. Late submissions will be accepted upto 24 hours from the deadline. All late submissions will have a penalty of 3 marks. Submissions later than 24 hours after the deadline will not be accepted.

The sixth laboratory has exercises on optimization under uncertain scenarios.

Exercise 1[3 marks] Bindu Mills Ltd manufactures bread that must be produced at three mills and transported to 10 distribution centers. The per-unit cost of making bread at the three mills and their capacities (in 10,000's) is shown in the table below.

Plant	Capacity	Cost
1	120	8
2	90	7
3	100	9

The demand at distribution centers and the per unit transportation cost of transporting bread from each factory to each center is as shown in the table below.

Plant	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6	DC-7	DC-8	DC-9	DC-10	DC-11	DC-12
1	2	3	2	3	5	4.4	3.2	3	1.5	3	6.0	1.0
2	1.9	3	2.4	2.4	2	4.1	2.8	3	1.7	2	1.0	4.5
3	3.1	1.8	2.8	3.4	2	2.9	2.2	3.2	2	2.8	4.5	6.0
Total Demand	20	30	40	35	15	19	25	20	18	12	30	40

Suppose the bread is sold to the centers at 20 rupees per unit.

1. [**R**] How much quantity should each plant produce and how much should be shipped to each distribution center so that the total profit is maximized? Write an LP in your report.
2. Solve the LP with the above data and display the solution in a readable format.

Exercise 2[7 marks] Now suppose that there is uncertainty in demand. The demand of each center can fluctuate (high, medium and low) independent of each other. Assume that at each center the medium demand is as shown in the above table, the low demand is 30% below medium and high demand is 30% above medium level. Further assume that probabiliy of low demand on a day is 0.3 and that of high demand is 0.3 (independently for each center).

The bread must be produced today before any sales (tomorrow) are observed. Once all distribution centers place their demand, we can transport the desired quantities to each center. We can not produce any quantity after the demands become known. How much should we produce and how much should be shipped to each center? Assume any unsold bread at the factories is sold in scrap at 5 rupees per unit. Any lost sale due to insufficient stock in a factory incurs a penalty of 7 rupees per unit.

One can write a two-stage stochastic linear program to model this problem. There are two types of variables here: (1) first stage variables: the quantity to produce, and (2) the second stage variables: the quantity to be shipped to various centres. Notice that even though the second stage variables can be decided only after the uncertainty is revealed, we can enumerate all possible scenarios and choose an appropriate value of the first stage variables that maximizes the expected profit. Also notice that the value of the first stage variables should not depend on which scenario is observed in the second stage. Thus, we can have one copy of second stage variables for each scenario.

1. [**R**] Try to write an LP model that maximizes the expected profit in this setting.
2. [**R**] How many different scenarios are possible? How many constraints and variables will there be in your model for the above example?
3. In what fraction of scenarios will we have more demand than total capacity?
4. Solve the above model. What are the optimal values of production quantitities, and what is the expected profit?

5. Compare the two solutions (deterministic LP vs stochastic LP) in terms of quantities produced at the three plants.