1 OPERATIONS RESEARCH

Question 1. (20 marks)
Modeling: The classical capacitated Vehicle Routing Problem (VRP) is a problem where a set of delivery requests (that is, N) have to be fulfilled from a single central depot with a fleet of vehicles with the same capacity of Q.

(i) In the course, we saw 3 models for the VRP. That is, the 2 index, 3 index and set partitioning formulations. Write your favorite formulation, and properly define the variables, each set, constraints, and objective function.**(12 marks)**

(ii) In the Vehicle Routing Problem, sometimes routes have intra-route constraints that each route must satisfy. Describe 2 intra-route constraints for the VRP and explicitly write down the corresponding equation for each constraint. The constraints do not necessarily have to be part of the previous formulation. **(8 marks)**

Continuation Answer Q1:

Continuation Answer Q1:

Question 2. (20 marks)
Metaheuristics

(i) What are heuristic methods and why are they used instead of exact methods? Explain and justify your answer.
(5 marks)

(ii) How can we evaluate the quality of a heuristic method?
(5 marks)

(iii) In the course, we saw different heuristics to solve the Traveling Salesman Problem. For example, 2-opt, Simulated annealing, nearest-neighbor, etc. Describe clearly each step of your favorite heuristic, with pseudo code.
(10 marks)

Continuation Answer Q2:

Continuation Answer Q2:

Question 3. (20 marks)
Shortest Path Problems

(i) What is the difference between the shortest path problem, shortest path problem with resource constraints and the elementary shortest path problem with resource constraints. Explain and justify your answer. **(3 marks)**

(ii) In the context of the shortest path problem, describe explicitly what is the "principal of optimality". **(7 marks)**

(iii) To solve shortest path problems we can use a labeling algorithm, what is a label?**(4 marks)**

(iv) In a labeling algorithm what are the feasibility checks and dominance rules used for? Explain and justify your answer.**(6 marks)**

Continuation Answer Q3:

Question 4. (20 marks)

Exact methods:

In the following multiple choice questions (4.1 and 4.2) mark with an $\mathcal{X}$ the correct answer.

Question: 4.1

In a combinatorial optimization problem like the Vehicle Routing Problem, what is a relaxation of the problem. **(3 marks)**

- ☐ A relaxation is when we replace the objective function with a linear expression and eliminate some feasible solutions.
- ☐ A relaxation is a new problem that results from removing some constraints from the original problem without eliminating feasible solutions.
- ☐ A relaxation is a new problem that adds new variables that are not binary to eliminate some feasible solutions.
- ☐ A relaxation is a new problem obtained by removing some variables and adding them at a later step.

Question: 4.2

What is an ng-route:**(3 marks)**

- ☐ A route that cycles only with close neighbors.
- ☐ A route that has no cycles.
- ☐ A route that has cycles only when distant neighbors are in the cycle.
- ☐ A route that violates resource constraints.

Question: 4.3

At each iteration of a Branch-and-Bound algorithm we have to select a node of the enumeration tree to evaluate, one way to select a node is to select one randomly. However, there are other more intelligent ways to select a node in the enumeration tree. Write down and explain a node selection strategy that would be better than just randomly selecting a node. **(14 marks)**

Continuation Answer Q4: