

Name: _____

- **One sided** 8.5 by 11 inch formula/note sheet is allowed.
- Show work clearly and neatly.
- Define all notation used.
- Please read each question carefully. If you are not sure what a question is asking, ask for clarification.
- If you start over on a problem, please **CLEARLY** indicate what your final answer is, along with its accompanying work.

Grade Table (for teacher use only)

Question	Points	Score
1	45	
2	55	
Total:	100	

Please write the following statement and sign it.

The Naval Service I am a part of is bound by honor and integrity. I will not compromise our values by giving or receiving unauthorized help on this exam.

1. Anne Arundel County is determining locations for COVID booster shot clinics. They have enough vaccines to open two clinics, each of which would have an allotment of 100,000 booster shots. The potential locations for clinics are Annapolis, Crofton, Severn, and Glen Burnie. The distance (in miles) between each of these potential vaccine clinics and cities they must serve, as well as the demand of each city, is given in the table below.

Clinic Locations	Distances (miles)						
	Annapolis	Crofton	Edgewater	Glen Burnie	Odenton	Parole	Severn
Annapolis	0	10	15	13	17	6	22
Crofton	10	0	17	9	11	16	27
Glen Burnie	17	11	12	0	7	14	11
Severn	22	27	6	8	11	20	0
Demand	35,000	15,000	12,000	50,000	7,000	11,000	47,000

To get started, the county has defined the following:

Sets

Let S be the set of possible clinic locations, $S = \{A, C, G, S\}$

Let C be the set of cities needing vaccines, $C = \{A, C, E, G, O, P, S\}$

Variables

Let $x_s = 1$ if a vaccine clinic is placed in location s and 0 otherwise for all $s \in S$

Let $y_{c,s} = 1$ if city c is assigned to vaccine clinic s for all $c \in C$ and all $s \in S$, and 0 otherwise.

- (a) (15 points) The county has decided that they want to place the clinics in order to minimize the total distance traveled by the people in each city (for example, if Crofton is assigned to Annapolis, then 15,000 people must travel 10 miles to a clinic leading to a cumulative distance traveled of 150,000).

Assume that if a city is assigned to a clinic, then that clinic will satisfy the entire demand for that city. Write an objective function, in both concrete and parameterized form, that would minimize this total distance traveled. Be sure to define any new parameters used.

- (b) (10 points) Since the county only has an allotment for 200,000 total vaccines, they can only open 2 clinics. Using the variables defined above, write a concrete constraint that ensures only two clinics are open.

- (c) (10 points) Since each clinic has an allotment of 100,000 vaccines, you realize that a capacity constraint also needs to be enforced. If the clinic is open, it should be allowed to serve only up to 100,000 people. If the clinic is closed, it should not be able to serve any customers.

Provide a parameterized constraint that enforces that if a clinic is open, it can service up to 100,000 units of total demand and if it's closed it can't service any demand. Be sure to clearly define any new parameters used.

- (d) (10 points) Lastly, you realize that you are missing a constraint linking your x_s variables and $y_{c,s}$ variables. Specifically, you should only be able to assign a city to a clinic if that clinic is open.

Write a concrete constraint which enforces that, if Annapolis is assigned to Crofton, then the clinic at Crofton must be open.

- (a) (20 points) The Dant is allowing the three drivers to split up the task of visiting these restaurants among the three of them. Assume that each driver must start at USNA and you must return after they've visited every restaurant, provide the (abbreviated) concrete integer programming formulation in order to complete the Dant's assignment. If an exponential number of constraints exist in your model, provide an example of at least two of them. Clearly define all decision variables required to model this problem.

- (b) (20 points) For the same problem, provide the parameterized integer programming model for solving the Dant's assignment. Clearly define all required decision variables, sets, and parameters not already provided to you.

- (c) (15 points) The Dant now realizes that he wants to make sure that Dwight, Kevin, and Oscar don't exceed 2500 calories while visiting their sequence of restaurants. The following table below includes the number calories that would be consumed if visited by one of the three reviewers:

	McD(1)	BK(2)	Pop(3)	CFA(4)	PF(5)	B(6)	EC(7)	C(8)	PH(9)	DP(10)
Cal.	800	750	850	600	550	700	900	450	550	650

Given this extra constraint, Dwight computed the following solution:

- Dwight visits restaurants in the order {USNA, McD, PF, B}
- Oscar visits restaurants in the order {USNA, BK, EC, Pop, CFA}
- Kevin visits restaurants in the order {USNA, C, PH, and DP}

Is this solution feasible? If not, provide a concrete inequality that eliminates this solution as well as all other similar ones.