Vaccine and Antibiotic Model

In this setup, a breakout has occurred. Some in the population need treatment. The rest we will give vaccinations to. To prevent further outbreak, we do not want to provide prevention and treatment in the same locations. In this problem we use multi-objective programming to balance the distance infected and uninfected people have to travel while staying within budget.

Multi-objective Programming

Minimizing Average Total Distance for Population to Receive Treatment or Prevention

Decision Variables:

First-stage:

$\mathbf{y}_{47x1}$: Binary, wether or not to open a point of dispense at each site

T_{47x1} : Binary, whether to use a site for therapeutics (0 means use for vaccination if y = 1)

$A_{96x47x2}$: Binary, whether or not to assign zip-code i to site j for treatment r

Second stage:

S_{47x96} : Binary, wether or not to assign less than 10 medical professionals to a site in every scenario

M_{47x96} : Binary, wether or not to assign between 10 and 20 medical professionals to a site in every scenario

L_{47x96} : Binary, wether or not to assign more than 20 medical professionals to a site in every scenario

$U_{47x25x96}$: Binary, whether or not to utilize a site each day in each scenario

$X_{47x25x96}$: Integer, the number of medical professionals for each point of dispense for every time period for every scenario

$I_{47x25x96}$: Integer, the amount of inventory to hold every day out of 25 days for each of 47 sites in 96 scenarios

Parameters:

D_{96x47} : Travel distance from zipcode i to site j

$\mathbf{p}_{96x1}$: population of each zipcode

$\mathbf{e}_{3x1}$: efficiencies per medical professional for each dispense size (Small, Medium, Large)

o : First stage fixed cost (opening cost)

v : Second stage variable cost

f : Second stage daily fixed cost

w : medical professional wage

h : Per unit daily holding cost

K : A constant serving as the budget constraint

B_{96x96} : Binary, whether the population for a zipcode has an outbreak for each of the 96 scenarios

C : The number of available medical professionals

Helping Functions

Average Total Distance to get therapeutics $= z_1 = \sum_{k=1}^{96} \sum_{i=1}^{96} \sum_{j=1}^{47} \frac{1}{96} p_i B_{ik} D_{ij} A_{ij1}$

Average Total Distance to get vaccination $= z_2 = \sum_{k=1}^{96} \sum_{i=1}^{96} \sum_{j=1}^{47} \frac{1}{96} p_i (1 - B_{ik}) D_{ij} A_{ij2}$

Average Total Cost
$= \sum_{j=1}^{47} o y_j + \sum_{k=1}^{96} \sum_{j=1}^{47} \sum_{i=1}^{96} \frac{1}{96} v p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) + \sum_{k=1}^{96} \sum_{j=1}^{47} \sum_{t=1}^{25} \frac{1}{96} (w X_{jtk} + h I_{jtk} + f U_{jtk})$

Formulation

Minimize $\alpha z_1 + (1 - \alpha) z_2$

subject to

Average Total Cost $\leq K$

$\sum_{j=1}^{47} A_{ijr} = 1, \forall i, r$

$A_{ijr} \leq y_j, \forall i, j, r$

$A_{ij1} + (1 - T_j) \leq 1, \forall i, j$

$A_{ij2} + T_j \leq 1, \forall i, j$

$S_{jk} + M_{jk} + L_{jk} \leq y_j, \forall j, k$

$10 M_{jk} + 20 L_{jk} - 20(1 - U_{jtk}) \leq X_{jtk} \leq 10 S_{jk} + 20 M_{jk} + 1{,}000 L_{jk}$, $\forall j, t, k$

$\sum_{t=1}^{25} e_S X_{jtk} \geq \left(\sum_{i=1}^{96} p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) \right) - (1 - S_{jk})(\text{Total Population}), \forall j, k$

$\sum_{t=1}^{25} e_M X_{jtk} \geq \left(\sum_{i=1}^{96} p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) \right) - (1 - M_{jk})(\text{Total Population}), \forall j, k$

$\sum_{t=1}^{25} e_L X_{jtk} \geq \left(\sum_{i=1}^{96} p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) \right), \forall j, k$

$\sum_{j=1}^{47} X_{jtk} \leq C, \forall t, k$

$X_{jtk} \leq C U_{jtk}, \forall j, t, k$

$U_{jtk} \leq S_{jk} + M_{jk} + L_{jk}, \forall j, t, k$

$I_{jtk} + (1 - S_{jk})(\text{Total Population}) \geq \sum_{i=1}^{96} p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) - \sum_{1}^{t} e_S X_{jtk}, \forall j, t, k$

$I_{jtk} + (1 - M_{jk})(\text{Total Population}) \geq \sum_{i=1}^{96} p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) - \sum_{1}^{t} e_M X_{jtk}, \forall j, t, k$

$I_{jtk} + (1 - L_{jk})(\text{Total Population}) \geq \sum_{i=1}^{96} p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) - \sum_{1}^{t} e_L X_{jtk}, \forall j, t, k$

$I_{jtk} - (1 - S_{jk})(\text{Total Population}) \leq \sum_{i=1}^{96} p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) - \sum_{1}^{t} e_S X_{jtk}, \forall j, t, k$

$I_{jtk} - (1 - M_{jk})(\text{Total Population}) \leq \sum_{i=1}^{96} p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) - \sum_{1}^{t} e_M X_{jtk}, \forall j, t, k$

$I_{jtk} - (1 - L_{jk})(\text{Total Population}) \leq \sum_{i=1}^{96} p_i \left(B_{ik} A_{ij1} + (1 - B_{ik}) A_{ij2} \right) - \sum_{1}^{t} e_L X_{jtk}, \forall j, t, k$

$X_{jtk}, I_{jtk} \geq 0$, integer

$y_j, T_j, S_{jk}, M_{jk}, L_{jk}, A_{ijr}, U_{jtk} \geq 0$, binary