# Appendix 1: Linearization strategy

Due to the nonlinearity in the proposed model, it is required to linearize the model so that it can be solved by using IBM CPLEX Optimizer. Specifically, four auxiliary parameters are introduced into the model, which are given by

| | |
|---|---|
| $\mathcal{r}_{mr}^{(-i)}$ | Number of sent medical-item $\mathrm{m}$ is $i$ in point $r$. |
| $\mathcal{d}_{\mathrm{md}}^{(+i)}$ | Number of received medical-item $\mathrm{m}$ is $i$ in point $d$. |
| $\mathcal{p}_{\mathrm{mp}}^{(-i)}$ | Number of sent medical-item $\mathrm{m}$ is $i$ in point $p$. |
| $\mathcal{p}_{\mathrm{mp}}^{(+i)}$ | Number of received medical-item $\mathrm{m}$ is $i$ in point $p$. |

Then, the optimal discrete solution space can be constructed, which is given by

$$\mathcal{r}_{mr}^{(-i)} = 0, \dots, i, \dots, \mathrm{L}_{\mathrm{mr}} \quad \forall\, \mathrm{r} \in \mathcal{R}, \mathrm{m} \in \mathcal{M}. \tag{A1}$$

$$\mathcal{d}_{\mathrm{md}}^{(+i)} = 0, \dots, i, \dots, \max_{\xi} \mathrm{D}_{\mathrm{md}}^{\xi} - \mathrm{L}_{\mathrm{md}} \quad \forall\, \mathrm{d} \in \mathcal{D}, \mathrm{m} \in \mathcal{M}. \tag{A2}$$

$$\mathcal{p}_{\mathrm{mp}}^{(-i)} = 0, \dots, i, \dots, \mathrm{L}_{\mathrm{mp}} \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A3}$$

$$\mathcal{p}_{\mathrm{mp}}^{(+i)} = 0, \dots, i, \dots, \max_{\xi} \mathrm{D}_{\mathrm{mp}}^{\xi} - \mathrm{L}_{\mathrm{mp}} \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A4}$$

where $\mathrm{D}_{\mathrm{md}}^{\xi}$ and $\mathrm{D}_{\mathrm{mp}}^{\xi}$ are the demand for medical-item $\mathrm{m}$ in points $\mathrm{d}$ and $\mathrm{p}$. Next, four additional binary variables are defined to determine the optimal number of sent or received medical-item $\mathrm{m}$.

$$\gamma_{mr}^{(-i)} = \begin{cases} 1 & \text{if the number of sent medical} - \text{item } m \text{ is } i \text{ in point } r \\ 0 & \text{otherwise} \end{cases} \quad \forall\, \mathrm{r} \in \mathcal{R}, \mathrm{m} \in \mathcal{M}. \tag{A5}$$

$$\delta_{md}^{(+i)} = \begin{cases} 1 & \text{if the number of received medical} - \text{item } m \text{ is } i \text{ in point } d \\ 0 & \text{otherwise} \end{cases} \quad \forall\, \mathrm{d} \in \mathcal{D}, \mathrm{m} \in \mathcal{M}. \tag{A6}$$

$$\rho_{mp}^{(-i)} = \begin{cases} 1 & \text{if the number of sent medical} - \text{item } m \text{ is } i \text{ in point } p \\ 0 & \text{otherwise} \end{cases} \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A7}$$

$$\rho_{mp}^{(+i)} = \begin{cases} 1 & \text{if the number of received medical} - \text{item } m \text{ is } i \text{ in point } p \\ 0 & \text{otherwise} \end{cases} \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A8}$$

In addition, to further linearize the proposed model, four more auxiliary variables need to be defined, which are given by

$$\mathcal{x}_{mr}^{(-i)} = \begin{cases} 1 & \text{if } \alpha_{mr} > \gamma_{mr}^{(-i)} \\ 0 & \text{otherwise} \end{cases} \quad \forall\, r \in \mathcal{R}, \mathrm{m} \in \mathcal{M}. \tag{A9}$$

$$\mathcal{y}_{md}^{(+i)} = \begin{cases} 1 & \text{if } \beta_{md} > \mathcal{d}_{\mathrm{md}}^{(+i)} \\ 0 & \text{otherwise} \end{cases} \quad \forall\, \mathrm{d} \in \mathcal{D}, \mathrm{m} \in \mathcal{M}. \tag{A10}$$

$$z_{mp}^{(-i)} = \begin{cases} 1 & \text{if } \alpha_{mp} > \wp_{\mathrm{mp}}^{(-i)} \\ 0 & \text{otherwise} \end{cases} \qquad \forall\ \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A11}$$

$$z_{mp}^{(+i)} = \begin{cases} 1 & \text{if } \beta_{mp} > \wp_{\mathrm{mp}}^{(+i)} \\ 0 & \text{otherwise} \end{cases} \qquad \forall\ \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A12}$$

Thus, the proposed model can be reformulated as the following scenario-based stochastic linear programming model, which is given by

$$\begin{aligned} Min\,\Psi_1 = \sum_{m\in\mathcal{M}} \Bigg\{ & \sum_{d\in\mathcal{D}}\sum_{\xi\in\Xi} P_\xi \sum_{i=0}^{\max_\xi D_{md}^{\xi}-L_{md}} F_{md}^{\xi}\left(L_{md} + d_{md\xi}^{(+i)}\right) y_{md\xi}^{(+i)} + \sum_{p\in\mathcal{P}}\sum_{\xi\in\Xi} P_\xi \left[ \sum_{i=0}^{\max_\xi D_{mp}^{\xi}-L_{mp}} F_{mp}^{\xi}\left(\beta_{mp} + \wp_{mp\xi}^{(+i)}\right) z_{mp\xi}^{(+i)} - \sum_{i=0}^{L_{mp}} F_{mp}^{\xi}\left(L_{mp} - \wp_{mp}^{(-i)}\right) z_{mp}^{(-i)} \right] \\ & - \sum_{r\in\mathcal{R}}\sum_{\xi\in\Xi} P_\xi \sum_{i=0}^{L_{mr}} F_{mr}^{\xi}\left(L_{mr} - \gamma_{mr}^{(-i)}\right) x_{mr}^{(-i)} \Bigg\} \end{aligned} \tag{A13}$$

s.t.

Constraints (2) and (4)-(6).

$$\sum_{i=0}^{\max_\xi D_{md}^{\xi}-L_{md}} \delta_{md}^{(+\tau)} = 1 \qquad \forall\ d \in \mathcal{D}, m \in \mathcal{M}. \tag{A14}$$

$$\sum_{i=0}^{L_{mr}} \gamma_{mr}^{(-i)} = 1 \qquad \forall\ \mathrm{r} \in \mathcal{R}, \mathrm{m} \in \mathcal{M}. \tag{A15}$$

$$\sum_{i=0}^{L_{mp}} \rho_{mp}^{(-i)} = 1 \qquad \forall\ \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A16}$$

$$\sum_{\mathrm{i}=0}^{\max_\xi \mathrm{D}_{\mathrm{mp}}^{\xi}-\mathrm{L}_{\mathrm{mp}}} \rho_{mp}^{(+i)} = 1 \qquad \forall\ \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A17}$$

$$\beta_{md} = \sum_{i=0}^{\max_\xi D_{md}^{\xi}-L_{md}} \delta_{md}^{(+\tau)} d_{\mathrm{md}}^{(+i)} \qquad \forall\ d \in \mathcal{D}, m \in \mathcal{M}. \tag{A18}$$

$$\alpha_{mr} = \sum_{i=0}^{L_{mr}} \gamma_{mr}^{(-i)} r_{mr}^{(-i)} \qquad \forall\ \mathrm{r} \in \mathcal{R}, \mathrm{m} \in \mathcal{M}. \tag{A19}$$

$$\alpha_{mp} = \sum_{i=0}^{L_{mp}} \rho_{mp}^{(-i)} \wp_{\mathrm{mp}}^{(-i)} \qquad \forall\ \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A20}$$

$$\beta_{mp} = \sum_{\mathrm{i}=0}^{\max_{\xi} \mathrm{D}_{\mathrm{mp}}^{\xi} - \mathrm{L}_{\mathrm{mp}}} \rho_{mp}^{(+i)} \wp_{\mathrm{mp}}^{(+i)} \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A21}$$

$$\sum_{i=0}^{L_{mp}} \rho_{mp}^{(-i)} + \sum_{\mathrm{i}=0}^{\max_{\xi} \mathrm{D}_{\mathrm{mp}}^{\xi} - \mathrm{L}_{\mathrm{mp}}} \rho_{mp}^{(+i)} \leq 1 \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A22}$$

$$\rho_{mp}^{(+i)} \leq \sum_{\mathrm{i}=0}^{\max_{\xi} \mathrm{D}_{\mathrm{mp}}^{\xi} - \mathrm{L}_{\mathrm{mp}}} \rho_{mp}^{(+i)} \mathcal{N} \quad \forall\, \mathrm{h} \in \mathcal{H}, \mathrm{m} \in \mathcal{M}. \tag{A23}$$

$$\rho_{mp}^{(-i)} \leq \sum_{i=0}^{L_{mp}} \rho_{mp}^{(-i)} \mathcal{N} \quad \forall\, \mathrm{h} \in \mathcal{H}, \mathrm{m} \in \mathcal{M}. \tag{A24}$$

$$\alpha_{\mathrm{mr}} - \gamma_{\mathrm{mr}}^{(-\mathrm{i})} \geq \left(x_{\mathrm{mr}}^{(-\mathrm{i})} - 1\right)\mathcal{N} \quad \forall\, \mathrm{r} \in \mathcal{R}, \mathrm{m} \in \mathcal{M}. \tag{A25}$$

$$\alpha_{\mathrm{mr}} - \gamma_{\mathrm{mr}}^{(-\mathrm{i})} \leq x_{\mathrm{mr}}^{(-\mathrm{i})}\mathcal{N} \quad \forall\, \mathrm{r} \in \mathcal{R}, \mathrm{m} \in \mathcal{M}. \tag{A26}$$

$$\beta_{mp} - \wp_{\mathrm{mp}}^{(+i)} \geq \left(z_{mp}^{(+i)} - 1\right)\mathcal{N} \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A27}$$

$$\beta_{mp} - \wp_{\mathrm{mp}}^{(+i)} \leq z_{mp}^{(+i)}\mathcal{N} \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A28}$$

$$\alpha_{\mathrm{mp}} - \wp_{\mathrm{mp}}^{(-\mathrm{i})} \geq \left(z_{\mathrm{mp}}^{(-\mathrm{i})} - 1\right)\mathcal{N} \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A29}$$

$$\alpha_{\mathrm{mp}} - \wp_{\mathrm{mp}}^{(-\mathrm{i})} \leq z_{\mathrm{mp}}^{(-\mathrm{i})}\mathcal{N} \quad \forall\, \mathrm{p} \in \mathcal{P}, \mathrm{m} \in \mathcal{M}. \tag{A30}$$

$$\beta_{\mathrm{md}} - \delta_{\mathrm{md}}^{(+\mathrm{i})} \geq \left(y_{\mathrm{md}}^{(+\mathrm{i})} - 1\right)\mathcal{N} \quad \forall\, \mathrm{d} \in \mathcal{D}, \mathrm{m} \in \mathcal{M}. \tag{A31}$$

$$\beta_{\mathrm{md}} - \delta_{\mathrm{md}}^{(+\mathrm{i})} \leq y_{\mathrm{md}}^{(+\mathrm{i})}\mathcal{N} \quad \forall\, \mathrm{d} \in \mathcal{D}, \mathrm{m} \in \mathcal{M}. \tag{A32}$$

The objective function is reformulated as the Eq. (A13). Constraints (A14)-(A17) guarantee that only one solution is selected from discrete solution space. Constraints (A17)-(A21) determine the optimal numbers of sent and received medical supplies. Constraints (A22)–(A24) ensure that only sending or receiving medical supplies could happen. Constraints (A25) and (A26) ensure that the utility is counted only when $\alpha_{\mathrm{mr}}$ is greater than $\gamma_{\mathrm{mr}}^{(-\mathrm{i})}$. Constraints (A27) and (A28) ensure that the utility is counted only when $\beta_{mp}$ is greater than $\wp_{\mathrm{mp}}^{(+i)}$. Constraints (A29) and (A30) ensure that the utility is counted only when $\alpha_{\mathrm{mp}}$ is greater than $\wp_{\mathrm{mp}}^{(-\mathrm{i})}$. Constraints (A31) and (A32) ensure that the utility is counted only when $\beta_{\mathrm{md}}$ is greater than $\delta_{\mathrm{md}}^{(+\mathrm{i})}$.