Supplementary file 1

The first MILP model:

The first MILP model is developed based upon the predetermined assignment of specialists to shifts and labs. This model determines the number of echos of each type that should be performed in each shift and by each specialist. The following sets, parameters and decision variables are used by the first MILP.

Sets and Indices

T	Set of all shifts in the planning horizon, indexed by t	$T = \{1,2, \dots, t, \dots, |T|\}$
J	Set of all specialists, indexed by j	S= $\{1,2, \dots, j, \dots |J|\}$
I	Set of all echo types, indexed by i	$I = \{1,2, \dots, i, \dots |I|\}$
L	Set of all echo labs, indexed by l	$L = \{1,2, \dots, |L|\}$

Parameters

A_{jtl} $\begin{cases} 1, \text{if specialist } j \text{ is assigned to echo lab } l \text{ in shift } t \text{ based on the predetermined timetable} \\ 0, \text{otherwise} \end{cases}$

S_{ij} $\begin{cases} 1, \text{if echo type } i \text{ can be performed by specialist } j \text{ (regarding specialist's specialty level)} \\ 0, \text{otherwise} \end{cases}$

E_{il} $\begin{cases} 1, \text{if the facility needed by echo type } i \text{ is available in echo lab } l \\ 0, \text{otherwis} \end{cases}$

P_{ij} The expected duration of echo of type i performed by specialist j

WH_{lt} The regular available time of echo lab l in shift t

TO_{lt} The maximum allowable overtime of echo lab l in shift t

MO_j The total allowable overtime for specialist j in the planning horizon

D_i The total demand of echo type i in the planning horizon

K_i The minimum number of echos of type i that should necessarily be performed within this planning horizon

CO   Overtime disutility per hour

W_i The utility of performing each echo of type i

M   A large number

Decision Variables

X_{itl} The number of echos of type i assigned to shift t to be performed in lab l

OH_{tj} The required overtime for specialist j in shift t

The second MILP model:

The second MILP model assigns specialists to different labs in different shifts and determines the number of patients of each type that should be assigned to each specialist-lab-shift simultaneously. In this model, the definitions of all sets, parameters S_{ij}, E_{il}, P_{ij}, WH_{lt}, MO_j, TO_{lt}, D_i, K_i, CO, W_i and M, and decision variables X_{itl} and OH_{tj} are the same as those of the first model. However, the following parameters and decision variable have been added.

Parameters

ZL_j The minimum allowable hours to work for specialist j in the planning horizon

ZU_j The maximum allowable hours to work for specialist j in the planning horizon

F_{jt} $\begin{cases} 0, \text{if specialist } j \text{ is unwilling to work in shift } t \\ 1, \text{otherwise} \end{cases}$

Decision Variable

Y_{jlt} $\begin{cases} 1, \text{if specialist } j \text{ is assigned to lab } l \text{ in shift } t \\ 0, \text{otherwise} \end{cases}$