Cleveland Clinic - Medical Resource Optimization Mathematical Formulation

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Dimensions

$r \in Resources$: set of resources

$f \in Facilities$: set of facilities

$sl \in Service\ lines$: set of service lines

$ss \in Sub-services$: set of sub-services

$io \in Inpatient/Outpatient$: set of Inpatient/Outpatient indicator

$ms \in Medical/Surgical$: set of Medical/Surgical indicator

$d \in Days$: set of days

$w \in Weeks$: set of weeks

$q \in Phase\ start\ dates$: set of phase start dates

Data Parameters: Model Coefficients

$capacity_{f,sl,ss,r}$ is the capacity of resource r at facility f, service line sl, sub-service ss

$utilization_{f,sl,ss,io,ms,r}$ is the usage of resource r per patient per day at facility f, service line sl, sub-service ss, for inpatient/outpatient indicator io, and medical/surgical indicator ms

$revenue_{f,sl,ss,io,ms}$ is the revenue per patient at facility f, service line sl, sub-service ss, for inpatient/outpatient indicator io, and medical/surgical indicator ms

$margin_{f,sl,ss,io,ms}$ is the margin per patient at facility f, service line sl, sub-service ss, for inpatient/outpatient indicator io, and medical/surgical indicator ms

$demand_{f,sl,ss,io,ms,d}$ is the maximum demand of facility f, service line sl, sub-service ss, and day d, for inpatient/outpatient indicator io, and medical/surgical indicator ms

$losMean_{f,sl,ss,io,ms}$ is the mean hospitalization time of facility f, service line sl, sub-service ss, for inpatient/outpatient indicator io, and medical/surgical indicator ms

$minday$ is the minimum day among the set $d \in Days$, $\min_{d \in Days} d$

$maxday$ is the maximum day among the set $d \in Days$, $\max_{d \in Days} d$

$dlyRapidTest_d$ is the total daily rapid tests available across all facility f, service line sl, sub-service ss, for inpatient/outpatient indicator io, and medical/surgical indicator ms

$dlyNonRapidTest_d$ is the total daily non-rapid tests for COVID-19 available across all facility f, service line sl, sub-service ss, for inpatient/outpatient indicator io, and medical/surgical indicator ms

$week_d$ is the week number of day d in set $d \in Days$

$daysBeforeSurgAdm$ is the number of days before which a surgery patient should be tested for COVID-19 (using a non-rapid test kit)

$fracInpTest$ is the fraction of inpatients tested for COVID-19 using the rapid test kit on the day of admission

$minDemRatio$ is the minimum proportion of demand that must be satisfied at a sub-service ss if its is open at a facility f, service line sl

$newPntBfCovid_{f,sl,ss,io,ms,d}$ is the new patients admitted without COVID-19 test constraints at the facility f, service line sl, sub-service ss, for inpatient/outpatient indicator io, and medical/surgical indicator ms on day d

$fixOpenFlag_{f,sl,ss}$ is a flag and is set to 1 if the facility f, service line sl, sub-service ss is open, 0 otherwise.

$emerSurRatio_{f,sl,ss}$ is a proportion of emergency surgical patients at the facility f, service line sl, sub-service ss.

$numCancel_{f,sl,ss,io,ms}$ is the maximum number of patients cancelled at the facility f, service line sl, sub-service ss, for inpatient/outpatient indicator io, and medical/surgical indicator ms

$maxUtil_r$ is the maximum proportion of utilization for the resource r

Decision Variables

$NewPatients_{f,sl,ss,io,ms,d} \geq 0$ is the number of patients accepted in facility f, service line sl, sub-service ss, on day d, for inpatient/outpatient indicator io, and medical/surgical indicator ms.

$ReschedulePatients_{f,sl,ss,io,ms,d} \geq 0$ is the number of patients rescheduled in facility f, service line sl, sub-service ss, on day d, for inpatient/outpatient indicator io, and medical/surgical indicator ms.

$OpenFlg_{f,sl,ss,d} \in \{0,1\}$ is the binary variable indicating if facility f, service line sl, sub-service ss is open on day d.

Variables

$TotalPatients_{f,sl,ss,io,ms,d}$ is the total number of patients accepted and rescheduled in facility f,service line sl, sub-service ss, cumulative for day d , for inpatient/outpatient indicator io, and medical/surgical indicator ms where,

$$TotalPatients_{f,sl,ss,io,ms,d} = \sum_{\substack{d1 \in d \text{ and} \\ \max\{[d - losMean_{f,sl,ss,io,ms}+1], \\ minday\} \leq d1 \leq d}} (NewPatients_{f,sl,ss,io,ms,d1} + ReschedulePatients_{f,sl,ss,io,ms,d1})$$

$$\forall f, sl, ss, io, ms, d$$

Objective Functions

$max \quad TotalRevenue = \sum_{f,sl,ss,io,ms,d} (NewPatients_{f,sl,ss,io,ms,d} + ReschedulePatients_{f,sl,ss,io,ms,d})\, revenue_{f,sl,ss,io,ms}$

$max \quad TotalMargin = \sum_{f,sl,ss,io,ms,d} (NewPatients_{f,sl,ss,io,ms,d} + ReschedulePatients_{f,sl,ss,io,ms,d})\, margin_{f,sl,ss,io,ms}$

Constraints

Maximum demand constraint: Number of patients accepted for f, sl, ss, io, ms should be less than the maximum demand for day d.

$$NewPatients_{f,sl,ss,io,ms,d} \leq demand_{f,sl,ss,io,ms,d}\, OpenFlg_{f,sl,ss,d} \quad \forall f, sl, ss, io, ms, d \tag{1}$$

Capacity constraint: Resources used for the total number of patients for f, sl, ss on day d should be less than equal to available capacity of resource r times the max utilization allowed for the resource at f, sl, ss. Currently, $maxUtil_r$ is defined only for r = 'ICU BEDS'; $maxUtil_r = 1$ for all other resources.

$$\sum_{io,ms} utilization_{f,sl,ss,io,ms,r}\ TotalPatients_{f,sl,ss,d} \leq capacity_{f,sl,ss,r}\ maxUtil_r \quad \forall f, sl, ss, d, r \tag{2}$$

Rescheduling constraint: Rescheduling patients for f, sl, ss, io, ms on day d is not allowed if the sub-service is not open

$$ReschedulePatients_{f,sl,ss,io,ms,d} \leq numCancel_{f,sl,ss,io,ms}\ OpenFlg_{f,sl,ss,d} \quad \forall f, sl, ss, io, ms, d \tag{3}$$

Maximum rescheduling constraint: Total number of rescheduled patients across all days for f, sl, ss, io, ms should be less than the maximum number of rescheduled patients.

$$\sum_{d} ReschedulePatients_{f,sl,ss,io,ms,d} \leq numCancel_{f,sl,ss,io,ms} \quad \forall f, sl, ss, io, ms \tag{4}$$

Minimum proportion of demand constraint: If a sub-service ss is open at f, sl then, we should at the least satisfy a minimum proportion of the weekly demand of f, sl, ss.

$$\begin{aligned} \sum_{\substack{io,ms,d \text{ and} \\ week_d = w}} (NewPatients_{f,sl,ss,io,ms,d} + ReschedulePatients_{f,sl,ss,io,ms,d}) \geq minDemRatio \\ \sum_{\substack{io,ms,d \text{ and} \\ week_d = w}} newPntBfCovid_{f,sl,ss,io,ms,d}\ OpenFlg_{f,sl,ss,d} \quad \forall f, sl, ss, w \end{aligned} \tag{5}$$

COVID-19 inpatient tests constraint: Total number of inpatients accepted (excluding surgical patients) and the emergency surgical patients admitted for f, sl, ss, ms on day d should be less than the total rapid test available daily rapid test available.

$$\begin{aligned} \sum_{\substack{f,sl,ss,io,ms \\ \text{and } io='I' \\ \text{and} \\ ms!='SURG'}} (NewPatients_{f,sl,ss,io,ms,d} + ReschedulePatients_{f,sl,ss,io,ms,d}) + \sum_{\substack{f,sl,ss,io,ms \\ \text{and} \\ ms='SURG'}} (NewPatients_{f,sl,ss,io,ms,d} \\ + ReschedulePatients_{f,sl,ss,io,ms,d})\ emerSurRatio_{f,sl,ss} \leq (dlyRapidTest_d\ /fracInpTest) \quad \forall d \end{aligned} \tag{6}$$

COVID-19 surgery patient tests constraint: Total number of surgery patients who will be admitted for surgery after '$daysBeforeSurgAdm$' days for f, sl, ss, io in day d should be less than the the total non-rapid test available for the day d.

$$\sum_{\substack{f,sl,ss,io,ms \text{ and} \\ d1=[d+daysBeforeSurgAdm] \\ \text{and } d1 \in d \\ \text{and} \\ ms='SURG'}} (NewPatients_{f,sl,ss,io,ms,d1} + ReschedulePatients_{f,sl,ss,io,ms,d1}) \\ (1 - emerSurRatio_{f,sl,ss})) \leq dlyNonRapidTest_d \quad \forall d \tag{7}$$

Sub-service open constraint: If a sub-service ss is open at f, sl on day d then it should be open for the remainder of the horizon.

$$OpenFlg_{f,sl,ss,d+1} \geq OpenFlg_{f,sl,ss,d} \quad \forall f, sl, ss, d \text{ and } d1 \in d \tag{8}$$

Sub-service already opened constraint: If a sub-service ss is already opened at f, sl then we set $OpenFlg$ variable as 1 for the entire planning horizon.

$$OpenFlg_{f,sl,ss,d} = 1 \quad \forall f, sl, ss, d \text{ and } d = minday \text{ and } fixOpenFlag_{f,sl,ss} = 1 \tag{9}$$

Sub-service open on phase date constraint: The sub-service ss allowed to open only on the phase dates or on the first day of the planning horizon.

$$OpenFlg_{f,sl,ss,d} = OpenFlg_{f,sl,ss,d-1} \quad \forall f, sl, ss, d \text{ and } (d-1) \in d \text{ and } d \notin q \tag{10}$$