

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

$icu \in ICU\ Resources$: set of ICU resources

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

$maxUtil_f$ is the maximum utilization allowed for ICU resource at the facility f

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,

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

Objective Functions

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

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

Constraints

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

$$NewPatients_{f,sl,ss,io,ms,d} \leq demand_{f,sl,ss,io,ms,d} \text{ OpenFlg}_{f,sl,ss,d} \quad \forall f, sl, ss, io, ms, d \quad (1)$$

Capacity constraint: Resources used for the total number of patients for f, sl, ss on day d should be less than or equal to available capacity of resource r .

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

Max. ICU resource utilization constraint: The utilization of ICU resources at f on day d should be less than or equal to the available capacity of resource r times the max utilization allowed for these resource at f .

$$\sum_{\substack{sl, ss, io, ms, r \\ \text{and } r \in icu}} utilization_{f, sl, ss, io, ms, r} TotalPatients_{f, sl, ss, d} \leq \sum_{\substack{sl, ss, r \\ \text{and } r \in icu}} capacity_{f, sl, ss, r} maxUtil_f \quad \forall f, d \quad (3)$$

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

$$ReschedulePatients_{f, sl, ss, io, ms, d} \leq numCancel_{f, sl, ss, io, ms} OpenFlg_{f, sl, ss, d} \quad \forall f, sl, ss, io, ms, d \quad (4)$$

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.

$$\sum_d ReschedulePatients_{f, sl, ss, io, ms, d} \leq numCancel_{f, sl, ss, io, ms} \quad \forall f, sl, ss, io, ms \quad (5)$$

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 .

$$\sum_{\substack{io, ms, d \text{ and} \\ week_d = w}} (NewPatients_{f, sl, ss, io, ms, d} + ReschedulePatients_{f, sl, ss, io, ms, d}) \geq minDemRatio \quad (6)$$

$$\sum_{\substack{io, ms, d \text{ and} \\ week_d = w}} newPntBfCovid_{f, sl, ss, io, ms, d} OpenFlg_{f, sl, ss, d} \quad \forall f, sl, ss, w$$

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.

$$\sum_{\substack{f, sl, ss, io, ms \\ \text{and } io = 'I' \\ \text{and} \\ ms \neq 'SURG'}} (NewPatients_{f, sl, ss, io, ms, d} + ReschedulePatients_{f, sl, ss, io, ms, d}) + \sum_{\substack{f, sl, ss, io, ms \\ \text{and} \\ ms = 'SURG'}} (NewPatients_{f, sl, ss, io, ms, d} + ReschedulePatients_{f, sl, ss, io, ms, d}) emerSurRatio_{f, sl, ss} \leq (dlyRapidTest_d / fracInpTest) \quad \forall d \quad (7)$$

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 .

$$\sum_{\substack{f, sl, ss, io, ms \text{ and} \\ d1=[d+daysBeforeSurgAdm] \\ \text{and } d1 \in d \\ \text{and} \\ ms='SURG'}} (NewPatients_{f,sl,ss,io,ms,d1} + ReschedulePatients_{f,sl,ss,io,ms,d1}) \quad (8)$$

$$(1 - emerSurRatio_{f,sl,ss})) \leq dlyNonRapidTest_d \quad \forall d$$

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.

$$OpenFlg_{f,sl,ss,d+1} \geq OpenFlg_{f,sl,ss,d} \quad \forall f, sl, ss, d \text{ and } d1 \in d \quad (9)$$

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.

$$OpenFlg_{f,sl,ss,d} = 1 \quad \forall f, sl, ss, d \text{ and } d = minday \text{ and } fixOpenFlag_{f,sl,ss} = 1 \quad (10)$$

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.

$$OpenFlg_{f,sl,ss,d} = OpenFlg_{f,sl,ss,d-1} \quad \forall f, sl, ss, d \text{ and } (d-1) \in d \text{ and } d \notin q \quad (11)$$