Dual Resource Scheduling in Trauma Care Centre with Time Varying Patient Demand

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Abstract This paper presents an integrated approach for the dual resource (medical staff and emergency beds) scheduling at each Point of Care (PoC) under time-varying Patient arrival demand for trauma centers. Practical constraints, such as the number of beds available, the number of patients that can be treated simultaneously at each Point of Care (PoC), and the signing on/off medical staff, are considered. The objective is to reduce the Patient's waiting time before entering into Operation Theatre/discharged since the Patient's arrival to the hospital. The mixed-integer linear programming (MILP) technique is used to solve the resulting multi-objective to deliver medical staff scheduling (i.e., signing on and off times of medical staff) and bed requirements simultaneously. The reduction of waiting times with this proposed algorithm is analyzed. A case study is conducted based on real-life data from a trauma center in India. The proposed approach is compared with the practical approach being followed in the trauma center. This comparison shows the proposed approach's effectiveness, suggesting scheduling medical staff based on historic patient arrival patterns will help reduce Patient's waiting times before entering Operation Theatre since the patient arrival. There is an average improvement in total process times for patients by 30%, with enhancements considered at a critical PoC.

Keywords Emergency care · Capacity planning in trauma care center · Medical resources optimization · Point of care

1 Introduction

Timely support of emergency care is crucial for the recovery of the Patient in need of it. During workdays or weekends, the hourly rate of patient arrival varies and

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can be estimated from historical data. As patient arrival rates increase and beds become unavailable and the attention of medical personnel becomes saturated. Thus, the planning process demands great attention because the recovery of the Patient is strongly influenced by qualified and timely attention.

As shown in Fig. 1, the different stages of trauma treatment include external factors (ambulance services), internal factors (primary treatment and theatre of operations), and post-operative treatment. This paper focuses only on how to optimize primary treatment until the Patient arrives in an operating Theatre. The primary treatment section is considered in three broad categories: Human Resources, Physical Resources and Process—Organization and administration (Mock C, 2004). Traditionally, medical staff planning (Human Resources) and bed availability (Physical Resources) are planned only once, in the initial stages of setting up the trauma care center.

In general, failure to update the planning process can cause the trauma center to operate in a sub-optimal manner. Planning determines the number of beds and hours of employment of specialized, general, nursing and paramedical staff to meet the demand for incoming patients within the constraints of the infrastructure. The bed requirements at each PoC can be determined based on the historical patient arrival rates, based on which the feasible schedule of medical staff could be obtained for a given interval. We focus on integrating medical staff scheduling and bed requirement plans for a typical trauma care center. In this optimization problem, detailed explanations regarding the assumptions are given in Sect. 3.2. In this paper, an optimization model is proposed for the medical staff scheduling and bed circulation planning for a trauma care center, with an objective to minimize the waiting times of the patients before entering the operation theatre. A mixed-integer linear programming (MILP) model is formulated, where the time-varying patient demand, the medical staff scheduling, the connection of bed services at each Point of Care are included in the model formulation. The rest of this document is organized along the following lines. Section 2 provides a literature review on the effect of waiting times of the Patient due to their arrival rate. Section 3 provides a detailed problem statement and the assumptions for formulating the model. In Sect. 4, the optimization problem for patient demand-oriented medical staff scheduling is formulated. In Sect. 5, a case study in a local trauma care center at Lucknow in India and the implications of the model are discussed.

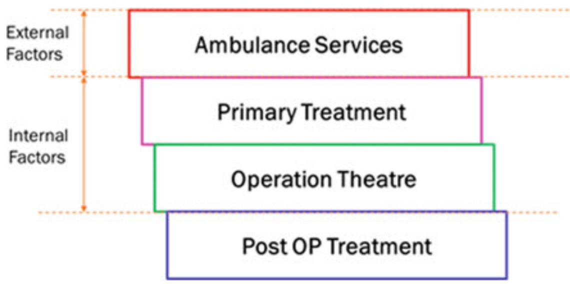

Fig. 1 Trauma Care delivery process

2 Literature Review

The purpose of a trauma care center is to stabilize patients who have a life-threatening or limb-threatening injury or illness and it focuses on the provision of immediate medical interventions [1]. After an accident or incident, the Patient is transported to the hospital by ambulance services. Pre-hospital emergency care is provided when the Patient needs life support until reaching the trauma center [2]. The trauma care center faces significant challenges in delivering high-quality, timely care to patients, given the increasing number of patients and limited hospital resources [3]. Several studies indicated that patient crowding contributes to reduced quality of patient care [4], treatment delays [5, 6], and worsens adherence with medical authority guidelines [7].

Modeling Approaches for Emergency department patient flow are classified into formula-based, regression-based, time-series analysis, queuing theory and Discrete Event Simulation [8]. The formula-based methodology employs past flow performance based on the number of staff and beds. Typical assessment tools include Emergency Department Work Index [9], Work Score [10, 11], Early Warning System and Demand Value [12]. They are straightforward and are used to divert ambulance services but do not have scalability and do not employ optimization techniques. The regression, a statistical technique uses the number of patients, determining patients' waiting times, staffing and information from other services, [13–15]. Due to inherent limitations in regression, for better handling, time-series based approaches are used for patient arrivals, bed occupancy, length of stay etc. [16–19]. The time-series method fails to capture the level of short-term variability. Queuing models help in optimal staffing and patient prioritization. These models generate relations between capacity, waiting times and treating process times. These models approximate patient arrival rates (Poisson/random) and flow patterns [20, 21]. They work on targeting discharging of patients within a set target. Discrete-event Simulation mime the models above with a graphical user interface helps in "What-If" analysis but cannot be used for "best-fit" models [8].

In this paper, we present an optimization model, with an objective to minimize the waiting times of the patients before entering the operation theatre by adaptively scheduling the medical staff based on patient arrival pattern. This would fetch better patient treatment satisfactorily and facilitates identification of bottleneck for future expansion plans. The average patient arrival rate at a trauma care center is around 15–20 per day in cities of India [22–25].

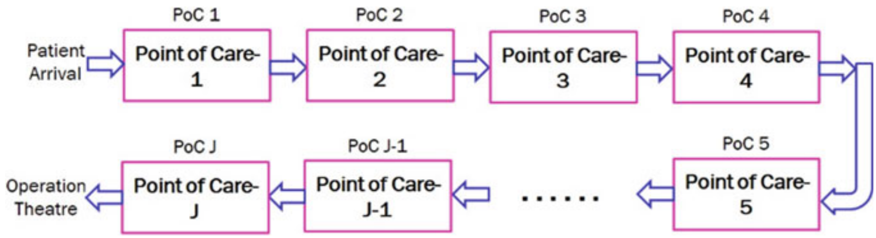

Fig. 2 Steps in emergency care delivery at the trauma center considered in the study

3 Problem Statement and Formulation

3.1 Problem Statement

We consider a trauma care center with the steps given in Fig. 2, where the patients can enter the trauma center from the Point of Care, PoC 1. Intended care is delivered to the patients at each Point of Care. The total number of PoCs is J. The patient treatment direction is from PoC 1 to J. Re-examination, and patient review at each Point Care is considered an additional PoC in the basic model. In a practical scenario, re-examination will be carried out at the earlier PoC. The number of patients treated simultaneously at each PoC depends on patient arrival and resource availability at the given PoC.

When considering medical staff scheduling problems for a trauma center, the inter-arrival time of patients changes several times; the incoming patient arrival rate in the peak hours may be significantly higher than that in the off-peak hours. Typical schedules for offering services to 4 patients in an hour, each arriving at an interval of 15 min, are shown in Fig. 3. This trauma center is assumed to have 9 PoCs before the Patient enters the Operation theatre. We propose to obtain Medical staff scheduling with the consideration of the number of simultaneous services to the Patient that can be offered at each Point of Care and patient demand to minimize the patients' total waiting time before entering into Operation Theatre.

3.2 Assumptions

The detailed descriptions of the assumptions to obtain Patient demand-oriented medical staff scheduling are described below:

(1) Each point where a Patient is observed, like primary care, fee counter, etc., is termed as a Point of Care (PoC);
(2) Patient in observation at a PoC cannot be set aside to treat another patient;
(3) Each bed in a PoC can accommodate only one Patient at a time;
(4) The available medical staff can be scheduled during the whole operating period;

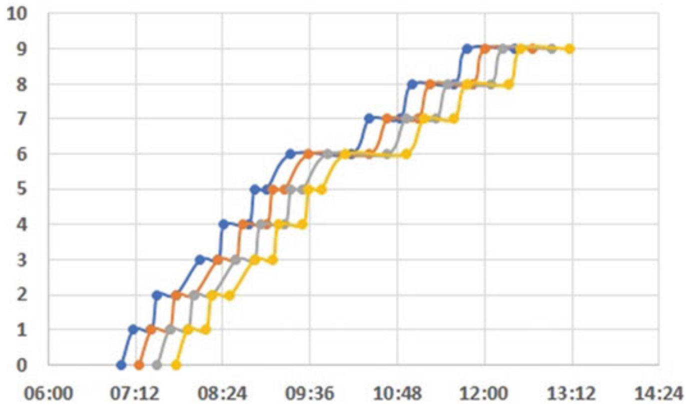

Fig. 3 Example of a patient treatment plan since arrival till entering operation theatre

(5) The medical staff can be scheduled for a continuous minimum and maximum working hours;
(6) The number of medical staff is the effective number after considering leave reserve and rest giver;
(7) There is a restriction on the maximum number of hours that medical staff can be called for working in a week.

4 Mathematical Formulations

The mathematical model is presented in this section to optimize the medical staff scheduling and bed requirement at each Point of Care. Initially, the notations and decision variables are discussed. Then, the constraints and objective functions of the patient arrival rate-based medical staff scheduling is formulated.

4.1 Notations and Decision Variables

The parameters and subscripts used in the model formulation are listed in Tables 1 and 2 lists the decision variables. Since the model is built based on patient arrival rates, the departure and arrival times at Point of Cares (PoCs), the transit times, waiting times and process times at each PoC are considered essential elements. Moreover, the availability of active beds at each PoC is a necessary aspect of planning. The considered possibilities include (1) whether the bed needs to activated or not, (2) whether the bed is to be deactivated or not immediately after the service to a patient, and (3) whether the same bed is to be used to serve the other Patient arrived later or not.

Table 1 Parameters and subscripts for the model formulation

Notations	Definition
$\mathbb{I}$	Set of patients {1,2,3,….I}
i, i'	Index of patients $i, i' \in \mathbb{I}$
$\mathbb{J}$	Set of point of care (PoC) {1,2,3,….J}
j, j'	Index of point of care $j, j' \in \mathbb{J}$
k	Number of time intervals in the operating period, where $k \in [1, 2, 3, \ldots, K]$
tra_j	Transit time from PoC j to $j+1$, j $\in \mathbb{J}/\{J\}$
$wt_{j,min}$	Minimal Waiting time for the process to start after arrival at PoC $j \in \mathbb{J}$
$wt_{j,max}$	Maximal Waiting time for the process to start after arrival at PoC $j \in \mathbb{J}$
$\tau_{i,j}$	Process time of patient i at point of care $j \in \mathbb{J}$
$\tau_{j,min}$	Minimum process time at PoC $j \in \mathbb{J}$
$\tau_{j,max}$	Maximum process time at PoC $j \in \mathbb{J}$
t_{start}	Start time of the trauma center services, $t_{start} = t_0$
t_{end}	End time of the trauma center services, $t_{end} = t_K$
p_k	Number of PATIENTS Arriving in time interval $\left[t_{k-1}, t_k\right)$ where $k \in [1, 2, 3, \ldots, K]$
λ_k	Patient arrival rates in time interval $\left[t_{k-1}, t_k\right)$ where $k \in [1, 2, 3, \ldots, K]$
$N_{bed,j}$	Maximum number of beds available at Point of Care $j \in \mathbb{J}$
M	Large number

Table 2 Decision variables for the model formulation

Notations	Definition
$pstart_{i,j}$	Process start time of patient $i \in \mathbb{I}$ at point of care j $\in \mathbb{J}$
$pend_{i,j}$	Process end time of patient $i \in \mathbb{I}$ at point of care j $\in \mathbb{J}$
$a_{i,j}$	Arrival time of patient $i \in \mathbb{I}$ at point of care j $\in \mathbb{J}$
$wt_{i,j}$	Waiting time of patient $i \in \mathbb{I}$ at point of care j $\in \mathbb{J}$
$\chi_{i,k}$	0–1 binary variable, $\chi_{i,k} = 1$, if the patient $i \in \mathbb{I}$ at point of care 1 in the interval $\left[t_{k-1}, t_k\right)$, Otherwise $\chi_{i,k} = 0$
$\xi_{i,j}$	0–1 binary variable, $\xi_{i,j} = 1$, if the new bed service is initiated to offer service to Patient $i \in \mathbb{I}$ at Point of Care j $\in \mathbb{J}$, Otherwise $\xi_{i,j} = 0$
$\delta_{i,j}$	0–1 binary variable, $\delta_{i,j} = 1$, if the bed service is withdrawn after service to Patient $i \in \mathbb{I}$ at Point of Care j $\in \mathbb{J}$, Otherwise $\delta_{i,j} = 0$
$\beta_{i,i',j}$	0–1 binary variable, $\beta_{i,i',j} = 1$, if the bed service at Point of Care j $\in \mathbb{J}$ is connected to offer service to Patient $i \in \mathbb{I}$ and $i' \in \mathbb{I}$, Otherwise $\beta_{i,i',j} = 0$

4.2 Constraints

In this subsection, constraints are discussed and formulated to generate a feasible schedule of the activation or deactivation of beds at each PoC based on the historic patient arrival rate.

Starting Constraints

The patient arrival rate has these scenarios as illustrated in Fig. 4, where the arrival rates of two successive patients are estimated to be the same in a given time interval, i.e., the patient arrival rate is constant between the arrival of Patient i and i−1 within the interval.

Assuming that only arrivals are possible in the same interval, then the arrival time of patent i at PoC 1 can be indicated as the following constraint:

$$a_{i,1} \leq t_{k,start} + tra_{i,1} + (m-1).\lambda_k \quad \forall i \epsilon I, k \epsilon K, m \in p_k \tag{1}$$

Arrival Constraints of Patient at each Point of Care.

The various time processes involved in patient movement from one Point of Care to another are shown in Fig. 5. The figure illustrates. Process end time, Arrival time and Process start time are flow variables, whereas the Process time, Transit time and Waiting time are the interval time variables.

The arrival time of patient i at Point of Care j is equivalent to the sum of the process end time at Point of Care $j-1$ and the transit time from the Point of Care $j-1$ to j, except for the first Point of Care. The arrival time of patient i at Point of Care j should satisfy the following constraint:

$$a_{i,j} = pend_{i,j-1} + tra_{i,j}\, \forall j \in \mathbb{J}/1 \tag{2}$$

Process Start Constraints of Patient at each Point of Care.

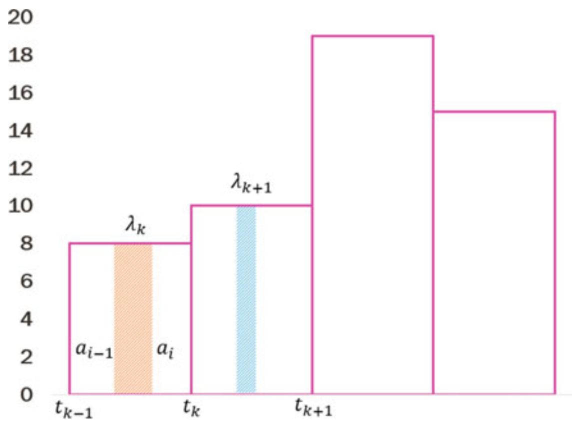

Fig. 4 Scenarios for calculation of Patient arrival

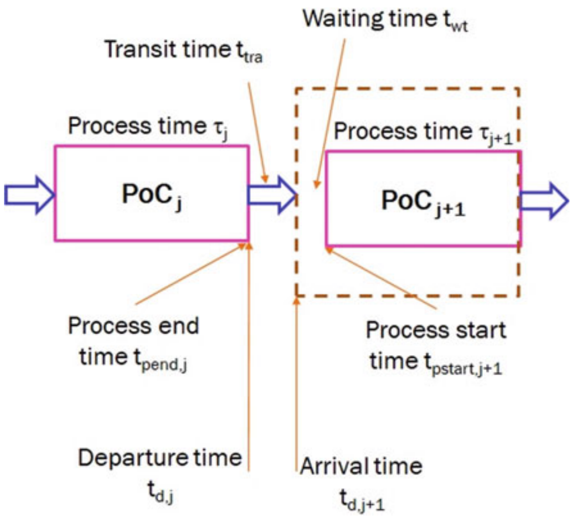

Fig. 5 Various times involved in patient movement from one point of care to another

The process start time of patient i at Point of Care j is equivalent to the sum of the arrival time and the waiting time at Point of Care j. The process start time of patient i at Point of Care j should satisfy the following constraint:

$$pstart_{i,j} >= a_{i,j} + wt_{i,j} \tag{3}$$

Since a patient being offered service cannot be kept aside for providing service to another patient, according to Assumption (2), the Patient's order of services holds the same for all the Point of Cares if the beds are available.

$$pstart_{i,j} - pend_{i-k,j} >= 0 \forall i > N_{beds,j} \; and \quad k = \{1, \ldots i\} \tag{4}$$

Process End Constraints of Patient at each Point of Care.

The process end time of patient i at Point of Care j is equivalent to the sum of the process start time and the process time at Point of Care j. The process start time of patient i at Point of Care j should satisfy the following constraint:

$$pend_{i,j} = pstart_{i,j} + \tau_j \tag{5}$$

Process time Constraints.

The process time of Patient i at Point of Care j should satisfy the following constraint:

$$\tau_{j,min} \leq \tau_{i,j} \leq \tau_{j,max} \tag{6}$$

Transit time Constraints.

The transit time of Patient i from Point of Care $j-1$ to j should satisfy the following constraint:

$$tra_{j,min} \le tra_{i,j} \le tra_{j,max} \tag{7}$$

Waiting time Constraints.

The Waiting time of Patient i from Point of Care j should satisfy the following constraint:

$$wt_{j,min} \le wt_{i,j} \le wt_{j,max} \tag{8}$$

Bed Constraints.

If services of patient i and i' utilize the same bed at Point of Care, then $\beta_{i,i',j} = 1$. However, if patient services i and i' does not utilize the same bed at Point of Care j, i.e., $\beta_{i,i',j} = 0$, then it means that they use different beds at Point of Care j. A large positive number M is introduced, and these constraints at PoC j are formulated as:

$$pend_{i',j} - a_{i,j} \ge wt_{j,min} - M\left(1 - \beta_{i,i',j}\right) \quad \forall i \epsilon \mathbb{I}/1, i' \epsilon \mathbb{I}, j \in \mathbb{J}/1 \tag{9}$$

$$pend_{i',j} - a_{i,j} \le wt_{j,max} + M\left(1 - \beta_{i,i',j}\right) \quad \forall i \epsilon \mathbb{I}/1, i' \epsilon \mathbb{I}, j \in \mathbb{J}/1 \tag{10}$$

When $\beta_{i,i',j} = 0$, i.e., patient i and patient i' does not use the same bed at PoC j, the constraints (9) and (10) become $pend_{i,j} - a_{i',j} \ge wt_{j,min} - M$ and $pend_{i,j} - a_{i',j} \le wt_{j,max} + M$ respectively. Due to the big M value, these values are satisfied. When $\beta_{i,i',j} = 1$, i.e., patient i and patient service i' use the same bed at PoC j, the constraints (9) and (10) become $pend_{i,j} - a_{i',j} \ge wt_{j,min}$ and $pend_{i,j} - a_{i',j} \le wt_{j,max}$, which mean that the patients at PoC j, satisfy the minimal and maximal waiting time constraints.

The bed assigned to provide service to a patient at PoC j can be initiated or can be the same used by earlier Patients. It means that when a current patient is offered service at a bed, it can be withdrawn or used to perform service to another patient. Based on the definitions of the binary variables $\xi_{i,j}$ and $\beta_{i,i',j}$ in Table 3, if there is no existing activated bed can be used to service patient i', i.e., $\sum_{i \in \mathbb{I}} \beta_{i,i',j} = 0$, then new bed for offering service to the patient i' must be assigned, if feasible else the Patient shall wait. Thus, the following constraint is formulated:

$$\xi_{i',j} = 1 - \sum_{i \in \mathbb{I}} \beta_{i,i',j} \tag{11}$$

If the bed serving patient i' is not new, then there must exist only one bed to service patient i', i.e., $\sum_{i \in \mathbb{I}} \beta_{i,i',j} = 1$, since $\xi_{i',j}$ is a binary variable and its maximum value is equal to 1. Thus, the following constraint is formulated:

Table 3 Sample Example

Patient No	Arrival time (minutes)	POC1 Process end time (minutes)	POC2 Process end time (minutes)	POC3 Process end time (minutes)	POC4 Process end time (minutes)	Total Process time (minutes)
P1	0	20	70	100	132	132
P2	13	33	83	113	147	134
P3	17	43	93	123	162	145
P4	24	53	103	133	177	153
P5	36	63	113	143	192	156

$$\sum_{i \in \mathbb{I}} \beta_{i,i',j} \leq 1 \tag{12}$$

If the bed after offering service to patient i is not offering further service within the interval, i.e., $\sum_{i' \in \mathbb{I}} \beta_{i,i',j} = 0$, then the bed after serving patient i is withdrawn from the operation. Otherwise, the bed after serving patient i continues to offer service to another patient. Thus, the following constraint is formulated:

$$\delta_{i,j} = 1 - \sum_{i' \in \mathbb{I}} \beta_{i,i',j} \tag{13}$$

Each bed can perform service to only one Patient at a time. Thus, the following constraint is formulated:

$$\sum_{i' \in \mathbb{I}} \beta_{i,i',j} \leq 1 \tag{14}$$

Also, if the same bed offers services to two patients i and i' with $i < i'$, when $\beta_{i,i',j} = 1$, then the bed serving patient i must not be withdrawn, i.e., $\delta_{i,j} = 0$. But this bed shall also perform service to patient i'. Hence, the bed serving patient i' does not require the new bed activated, i.e., $\xi_{i',j} = 0$. Thus, the bed activation should satisfy the following constraints:

$$\delta_{i,j} + \xi_{i',j} \leq M\left(1 - \beta_{i,i',j}\right) \tag{15}$$

$$\delta_{i,j} + \xi_{i',j} \geq -M\left(1 - \beta_{i,i',j}\right) \tag{16}$$

When $\beta_{i,i',j} = 0$, the constraints are given in (15) and (16) will be satisfied due to the big M.

Practically, the number of beds available for the activation is limited and is denoted by $N_{bed,j}$. When $\xi_{i',j} = 1$, i.e., the bed offering service to patient i being newly assigned, we need to check whether there are still beds available at PoC j to perform service to Patient i. Thus, the difference between the total number of beds deactivated from utilization and the total number of beds under utilization should be less than or equal to the number of available beds at that Point of Care, j. This condition can be formulated as:

$$\sum_{m=1}^{i} \xi_{m,j} - \sum_{m=1}^{i-1} \delta_{m,j} \leq N_{bed,j} \tag{17}$$

where $\sum_{m=1}^{i} \xi_{m,j}$ and $\sum_{m=1}^{i-1} \delta_{m,j}$ are the total number of beds activated and deactivated until the departure of patient service i from PoC j.

Patient Demand Constraints

The Patient arrival rates can be written as:

$$\tilde{\lambda}(t) = \begin{cases} \lambda_1, & if t \varepsilon [t_0, t_1) \\ \lambda_2, & if t \varepsilon [t_1, t_2) \\ & \cdots \\ \lambda_K, & if t \varepsilon \big[t_{K-1}, t_K\big) \end{cases} \tag{18}$$

whereas

$$\lambda_k = \frac{\kappa_k}{(t_k - t_{k-1})} \tag{19}$$

where κ_k is the number of patients arriving in the interval $[t_{k-1}, t_k)$. The operating period $[t_{start}, t_{end}]$ is split into K time slots with the splitting time instants $t_1, t_2, \ldots, t_{K-2}, t_{K-1}$ where t_0 is t_{start} and t_K is t_{end}. The patient arrival rates are assumed as Poisson distributed within the interval.

4.3 Objective Function

An even bed activation and deactivation plan at each PoC between successive patients entering into Operation theatre can reduce total waiting time, based on the patient arrival pattern. The objective function is to minimize the variation between the consecutive end time of the patient treatment process at each Point of Care to reduce the waiting time of the patients. In an ideal case, the inter-arrival time of patients shall be the same as the inter-departure time of patients to the operation theatre. Thus, an objective function is formulated as follows:

$$Minimize \sum_{i \in \mathbb{I}/1} \big(a_{i,1} - a_{i-1,1}\big) - \big(pend_{i,J} - pend_{i-1,J}\big) \tag{20}$$

Table 4 Various time parameters in Minutes at each Point of Care

Point of Care	Transit time to next PoC (Min)	Transit time to next PoC (Max)	Waiting time (Min)	Waiting time (Max)	Process time (Min)	Process time (Max)	Capacity of Patients treatment at each POC
POC1: Stretcher	20	30	10	40	10	15	2
POC2: Primary check	10	20	20	70	10	30	2
POC3: Cash payment	5	10	15	45	5	20	3
POC4: Lab investigation	2	5	120	240	15	120	1
POC5: Ultrasound investigation	5	15	10	30	10	20	2
POC6: Re-examination	10	25	15	45	10	45	1
POC7: Surgery ward	5	15	40	180	15	25	1
POC8: Surgeon check	5	10	30	120	10	20	1
POC9: Speciality Ward	15	20	130	240	5	15	2
POC10: Specialist check	5	20	15	90	5	20	1
POC11: Operation theatre	30	45	720	4320	20	45	1

To explain the objective function, a sample example assuming a typical hospital with four PoCs is discussed in Table 4. Let the Patients are arriving hospital at arrival times of 0,13,17,24 and 36 min. The total process time of each Patient is 132, 134, 145, 153 and 156 respectively. It can be seen that the process time on each Patient is increasing, if the Patient inter-arrival time is reducing. Ideally, the process time for all the patients should be same i.e., the difference between the process times of Patient i and his/her predecessor Patient $i - 1$ shall be Zero. Hence, the objective function is chosen to minimize the process times of two successive patients.

5 Case Study

The MILP programming is carried out through CPLEX (student version, for less than 1000 variables) and Matlab. The proposed model has been applied to a Trauma Center in Lucknow. The average number of cases seen daily is 110 and the average number of admissions through this center daily is 70 [1]. The center will function round the clock on all days throughout the year. There are 150 beds and ten operation theatres (five major and five minor). The layout of this trauma center is illustrated in Fig. 6. The detailed activities taken at each PoC are discussed in [2].

The transit, waiting and process time is shown in Table 4. Transit time and Process time are obtained from [2]. The minimum and maximum waiting times are obtained from the trauma center and represent the performance of the trauma center. The operating period of the trauma center is 24 h.

The patient arrivals are approximated in intervals of three hours based on the overall road accident rates in India [3]. The estimated patient arrivals are shown in Fig. 7. It can be noted that the peak hours are between 09:00 AM to 09:00 PM. Based on this historic arrival pattern, the number of facilities at each PoC can be put into operation at that time interval can be planned to minimize the patient waiting times.

If the capacity is doubled at each PoC, the percentage improvement is around 30%. See Table 5. The results of the first three Patient's travel are plotted in Fig. 8 as programmed in Matlab. Using the optimization model, it can be seen that most of

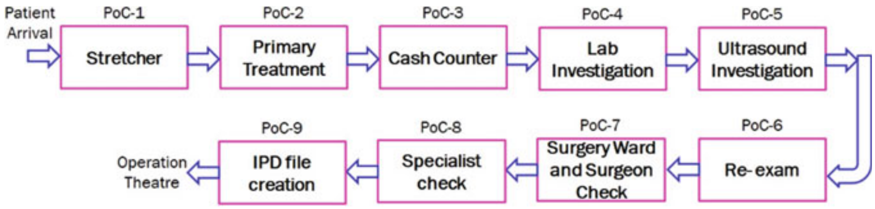

Fig. 6 The layout of Trauma center operations

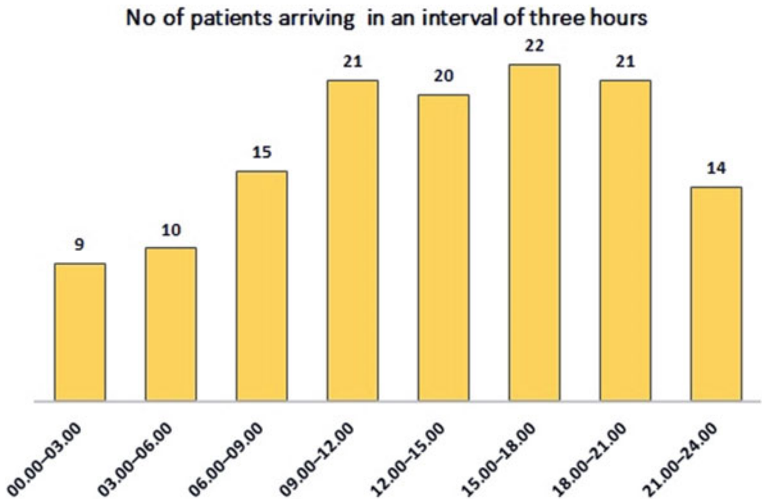

Fig. 7 Estimated Patient arrivals in three hours interval

the waiting time is available in PoC4. Now keeping bed capacity at all other PoCs as one and double the capacity at the PoC4 yielded almost similar results as shown in Table 6 with an only enhancement of capacity in PoC 4.

From the above, it can be seen that the performance of the hospital in terms of delivering care to the hospital can be optimized using this model. The ratio of beds activated to the staff requirement is constant. It can be obtained using multiplication

Table 5 Increase in the improvement of process time by doubling the capacity at each PoC

Patient No	Arrival time (minutes)	Process end time (minutes) till PoC4, when only one bed is operated in each PoC	Process end time (minutes) till PoC4, when two beds are operated in each PoC	Percentage improvement
P1	0	132	132	NA
P2	13	134	132	2%
P3	17	145	132	10%
P4	24	153	136	13%
P5	36	156	132	18%
P6	47	160	132	21%
P7	64	158	132	20%
P8	68	169	132	28%
P9	76	176	135	30%
P10	93	174	132	32%

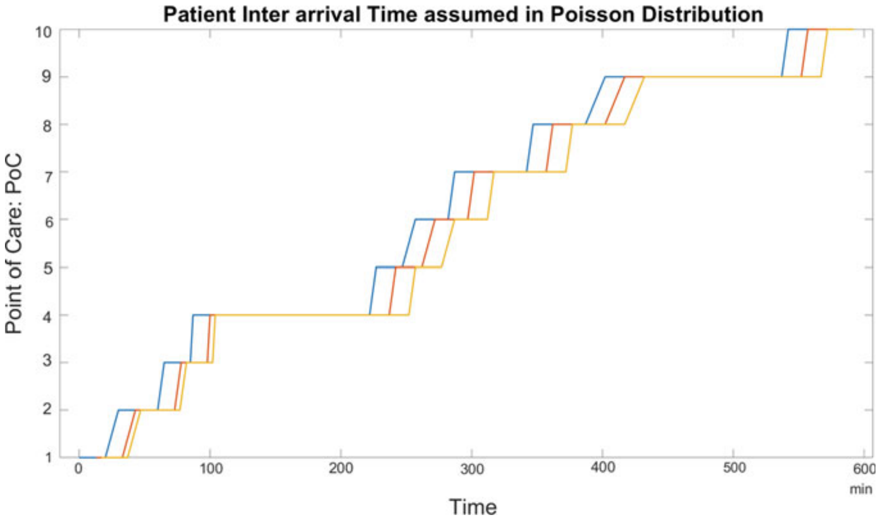

Fig. 8 The plot of the first three Patient's travel along the Point of Cares

Table 6 Increase in the improvement of process time by doubling the capacity only at PoC 4

Patient No	Arrival time (minutes)	Process end time (minutes) till PoC4, when only one bed is operated in each PoC	Process end time (minutes) till PoC4, when two beds are operated only in PoC 4	Percentage improvement
P1	0	132	132	NA
P2	13	134	132	2%
P3	17	145	138	5%
P4	24	153	141	9%
P5	36	156	139	12%
P6	47	160	138	16%
P7	64	158	132	20%
P8	68	169	138	22%
P9	76	176	140	26%
P10	93	174	133	31%

factor as per the standards of the hospital. For this purpose, the time slot for consideration can be three or four hours for scheduling the medical staff. In this manner, the dual resource scheduling based on patient arrival patterns can be achieved for that particular time interval.

6 Conclusions

In this paper, we have formulated a Mixed-Integer Linear Programming model for activation of the beds at each PoC. The optimization model's performance is compared with the practical approach followed by a trauma center in India. According to the results, the capacity enhancement at Critical PoCs can improve the hospital's performance in delivering timely care to the patients by optimizing the medical staff for that particular time interval. This helps in utilizing the scarce and valuable medical staff resources optimally while delivering quality and timely care to the Patients.

Further Research

The optimization can be included from the time of the accident, travel by ambulance, and completion of the operation theatre. The optimization can also consider the cost of enhancing capacity at a particular PoC in the workforce and additional equipment. The optimization can also be improved to evaluate the improvement in transit times and process times.

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