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A fuzzy rule-based efficient hospital bed management approach for coronavirus disease-19 infected patients

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Abstract

Coronavirus disease-19 (COVID-19) is a very dangerous infectious disease for the entire world in the current scenario. Coronavirus spreads from one person to another person very rapidly. It spreads exponentially throughout the globe. Everyone should be cautious to avoid the spreading of this novel disease. In this paper, a fuzzy rule-based approach using priority-based method is proposed for the management of hospital beds for COVID-19 infected patients in the worst-case scenario where the number of hospital beds is very less as compared to the number of COVID-19 infected patients. This approach mainly attempts to minimize the number of hospital beds as well as emergency beds requirement for the treatment of COVID-19 infected patients to handle such a critical situation. In this work, higher priority has given to severe COVID-19 infected patients as compared to mild COVID-19 infected patients to handle this critical situation so that the survival probability of the COVID-19 infected patients can be increased. The proposed method is compared with first-come first-serve (FCFS)-based method to analyze the practical problems that arise during the assignment of hospital beds and emergency beds for the treatment of COVID-19 patients. The simulation of this work is carried out using MATLAB R2015b.

Keywords Coronavirus · COVID-19 · Fuzzy rule-based approach · Priority-based method · FCFS-based method · Hospital bed management

1 Introduction

COVID-19 [1–48, 58] is a novel infectious disease on the global scale which is very dangerous in nature. This virus has declared as a global pandemic by World Health Organization (WHO) [58]. Currently, there are around 498 lakhs COVID-19 positive cases, 12.5 lakh death cases, and 215 countries are affected by this novel COVID-19 [58–60]. As this virus spreads from one person to another person rapidly an exponential manner, so every individual of different countries should focus on the following precautions to break the spreading chain of this virus.

- Social distancing
- Staying at home if no emergency work
- Use of masks at work as well as marketing places
- Cleaning of hand properly at regular intervals
- Avoid touching of face, eyes, mouth and nose
- Avoid mass gatherings

As the situation becomes very worst day by day, so it is very much essential to be ready with the hospital beds for the treatment of COVID-19 infected patients. However, in the practical scenario, the number of hospital beds available for the treatment of such patients is very less as compared to the number of infected cases due to the rapidly spreading of this disease. Hence, hospital bed management

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is a very challenging issue for the government of every country as well as states. In this work, a fuzzy rule-based approach using priority-based method is proposed to solve this serious issue by considering the worst-case scenario.

The main contributions of this work are stated as follows.

- A fuzzy rule-based approach using priority-based method is proposed to minimize the number of hospital beds and emergency beds requirement for the treatment of COVID-19 infected patients.
- This approach mainly focuses on the priority-based method where severe COVID-19 infected patients have assigned higher priority as compared to mildly infected patients to increase the survival probability of the patients.
- This approach is compared with the FCFS-based method to study the practical scenario of hospital beds as well as emergency beds assignments to the COVID-19 infected patients.
- The simulation of proposed work is carried out using MATLAB R2015b.

The rest of the paper is organized as follows. Section 2 describes related works, Sect. 3 describes the proposed methodology, Sect. 4 describes results and discussion, and Sect. 5 describes the conclusion of this work.

2 Related works

Different works have carried out by different researchers related to COVID-19 [1–48]. Some of the works are described as follows. Wong et al. [1] focused on the measurement of the response of operating room outbreak by considering a large tertiary hospital in Singapore. Meares et al. [2] emphasized on a system break mechanism as well as a queuing theory model that specifies regarding the requirement of intensive care beds during the COVID-19 pandemic. Tan et al. [3] focused on the preparation of the operating room for COVID-19 outbreak, and it mainly deals with the national heart center, Singapore. Huang et al. [4] emphasized on the infection control as well as management in an emergency situation against the spread of COVID-19 in a radiology department. Hick et al. [6] focused on the planning related to health care, crisis standards of care due to the spreading of novel coronavirus SARS-COV-2. Pu et al. [7] emphasized on the screening as well as management of confirmed or suspected COVID-19 patients by considering a tertiary hospital which is outside the Hubei province. Li et al. [11] focused on the demand for inpatient as well as ICU beds for the treatment of COVID-19 patients in the USA by analyzing the scenario of Chinese cities. Tanne et al. [15] emphasized on the mechanisms for the tackling of coronavirus on a global scale by the doctors as well as by the healthcare systems. Zunyou et al. [21] focused on the analysis of COVID-19 outbreaks in China to gain important lessons as well as characteristics from this situation by summarizing a report of 72,314 cases from the Chinese center for disease control and prevention. Roosa et al. [23] emphasized on the real-time forecasts in China from February 5, 2020, to February 24, 2020, related to COVID-19 epidemic.

3 Proposed methodology

In this work, we have focused on the scenario where the number of hospital beds (B) is very less as compared to the number of COVID-19 infected patients (C), i.e., B << C. So, it is a challenging task to assign the hospital beds to the COVID-19 infected patients efficiently in this scenario. The proposed work can provide a solution to handle this critical situation. This work mainly focuses on fuzzy rule-based approach [49–53] that uses priority-based method [54, 55] to manage and assign the hospital beds for the treatment of COVID-19 infected patients. The proposed approach is compared with the FCFS-based [56, 57] approach to analyze the practical scenario during the assignment of hospital beds. The fuzzy rule-based approach mainly focuses on the "IF–THEN" rule. When we consider "if P is X then Q is Y," then "P is X" is known as the premise and "Q is Y" is known as consequent. So, as per this rule, the consequent value will be decided by considering the premise value.

In our work, all the COVID-19 infected patients will be grouped into two categories such as mild and severe. As per the proposed approach, more priority is assigned to severe cases as compared to mild cases to increase the survival rate of the patients. So, by applying fuzzy rule-based approach using the priority-based method, if any patients with the severe category will arise, then they will be immediately assigned with the hospital beds for six weeks (42 days). After six weeks, severe patients will be either cured or dead, but they have to release the beds. If any patients with mild cases will arise, then they will be kept in home isolation with doctor's careful advice for two weeks (14 days) as the survival probability for these patients is high.

After two weeks if the patients with the mild case will be cured, then they will be careful for further days with doctor's advice; otherwise, these patients will be severe and will be assigned with hospital beds for next six weeks if the hospital beds are available in that situation. After six weeks, patients with mild cases will be cured. In case of unavailability of hospital beds, emergency beds will be assigned to the severe patients. The hospital beds as well as emergency beds will be properly sanitized as per COVID-19 guidelines before assign to COVID-19 infected patients. The proposed fuzzy rule-based approach is represented in Table 1. The proposed methodology is mentioned in Fig. 1. The proposed algorithm is mentioned in Algorithm 1.

then there may not be any bed available for the patients with severe cases which lead to the higher death rate. The FCFS-based mechanism is mentioned in Algorithm 2. As per the report, around 80% of cases are mild, 20% of cases are severe, and 5% cases lead to death out of total COVID-19 infected cases in the current scenario. It

Algorithm 1: Hospital Bed Assignment using proposed algorithm

Input: Number of COVID-19infected patients

Output: Minimum number of hospital beds required for treatment

```
Initialize b=0
For i=1 to n Covid-19 infected patients
  If p_i= = s_i      (p:patient, s:severe)
    then assign a hospital bed for 42 days
      b=b+1
      If no. of days > 42
        If ps_i= = cure  or  ps_i= = dead  (ps: patient severe)
          then release the hospital bed
              b=b-1
        End
      End
  End
  If p_i= = m_i      (p:patient, m:mild)
    then home isolation for 14 days  with doctor's advice
        If no. of days > 14
          If  pm_i = =cure
            then careful precautions for further days
          End
          If  pm_i = =ms_i  ( ms: mild changes to severe)
            then assign a hospital bed for the next 42 days, if available
              b=b+1
              If no. of days > 42
                If pms_i = = cure or pms_i = = dead
                  then release the hospital bed
                      b=b-1
                End
              End
          End
        End
    End
End
Display b (b: hospital beds status)
```

Whereas by applying FCFS-based method, all the COVID-19 infected patients will be assigned with hospital beds and it does not matter whether the cases are mild or severe. In this situation, it is very difficult to handle all the cases in the worst-case scenario and it may increase the death rate as compared to the survival rate. So, if more number of patients with mild cases will be assigned with hospital beds at the initial situation,

will take around two weeks to cure the patients with mild cases and around 6 weeks to cure the patients with severe cases. In this work, we have considered that 80% of cases are mild, 20% of cases are severe, 90% cases will be cured cases, and 10% cases will be death cases. A patient with a severe case will be either cured or dead after six weeks, and the patient with a mild case will be either cured or severe after two weeks.

Algorithm 2: Hospital Bed Assignment using FCFS based method

Input: Number of COVID-19 infected patients

Output: Minimum number of hospital beds required for treatment

```
Initialize b=0
For i=1 to n Covid-19 infected patients
 If p_i= = s_i      (p:patient, s:severe)
  then assign a hospital bed for 42 days
     b=b+1
     If no. of days > 42
        If ps_i= = cure  or  ps_i= = dead  (ps: patient severe)
            then release the hospital bed
                 b=b-1
        End
     End
  End
  If p_i= = m_i      (p:patient, m:mild)
   then assign a hospital bed for14 days
      b=b+1
        If no. of days > 14
            If pm_i = = cure
              then release the hospital bed
                 b=b-1
            End
            If  pm_i = =ms_i  ( ms: mild changes to severe)
              then occupy the same bed for the next 42 days
                 If no. of days > 42
                   If pms_i = = cure or pms_i = = dead
                      then release the hospital bed
                         b=b-1
                   End
                 End
            End
        End
  End
End
Display b (b: hospital beds status)
```

In our work, for severe cases, the probability of survival for the cure is assigned with 0.8 that means P_{Survival} (Severe-Cure) = 0.8 and the probability of survival for death is assigned with 0.2 that means P_{Survival} (Severe-Death) = 0.2. So, the total probability is 1 as the sum of probability of survival for cure and death case is 1. It is represented using Eq. 1.

$$P_{\text{Survival}}(\text{Severe-Cure}) + P_{\text{Survival}}(\text{Severe-Death}) = 1 \quad (1)$$

Similarly, for mild cases, the probability of survival for the cure is assigned with 0.8 that means P_{Survival} (Mild-Cure) = 0.8 and the probability of survival for the cases which will be changed from mild to severe is 0.2 that means P_{Survival} (Mild to Severe) = 0.2. So, the total probability is 1 and it is represented using Eq. 2.

$$P_{\text{Survival}}(\text{Mild-Cure}) + P_{\text{Survival}}(\text{Mild to Severe}) = 1 \quad (2)$$

When any mild case changes to the severe case, then its probability of survival will be changed to 0.5 that means P_{Survival} (ms) = 0.5 where ms represents that the mild case is changed to severe case. In this situation, we have considered the survival probability as 0.5 because after changing the mild case to severe case, the probability of survival depends on the availability of hospital bed and the patient will be cured if assigns with a bed for treatment immediately otherwise the probability for death will be higher. Hence, we have considered the probability as 0.5 in this case that means P_{Survival} (ms-Cure) = 0.5 and P_{Survival} (ms-Death) = 0.5 where P_{Survival} (ms-Cure) represents the probability of survival for cure and P_{Survival} (ms-Death) represents the probability of survival for death when mild case changes to severe case. So, the total probability is 1 and it can be represented using Eq. 3.

$$P_{\text{Survival}}(\text{ms-Cure}) + P_{\text{Survival}}(\text{ms-Death}) = 1 \quad (3)$$

In our work, we have referred the week-wise data of COVID-19 infected patients from February 2, 2020, to July 26, 2020, in India from the source [60] and it is mentioned

Table 1 Fuzzy rule-based approach using the priority-based method

Sl. no	Case	Action
1	Mild	Home isolation for 2 weeks with Doctor's advice
2	Severe	Assign hospital bed for 6 weeks
3	Mild cured after 2 weeks	Precautions for further days with Doctor's advice
4	Mild changed to severe after 2 weeks	Assign hospital bed for the next 6 weeks

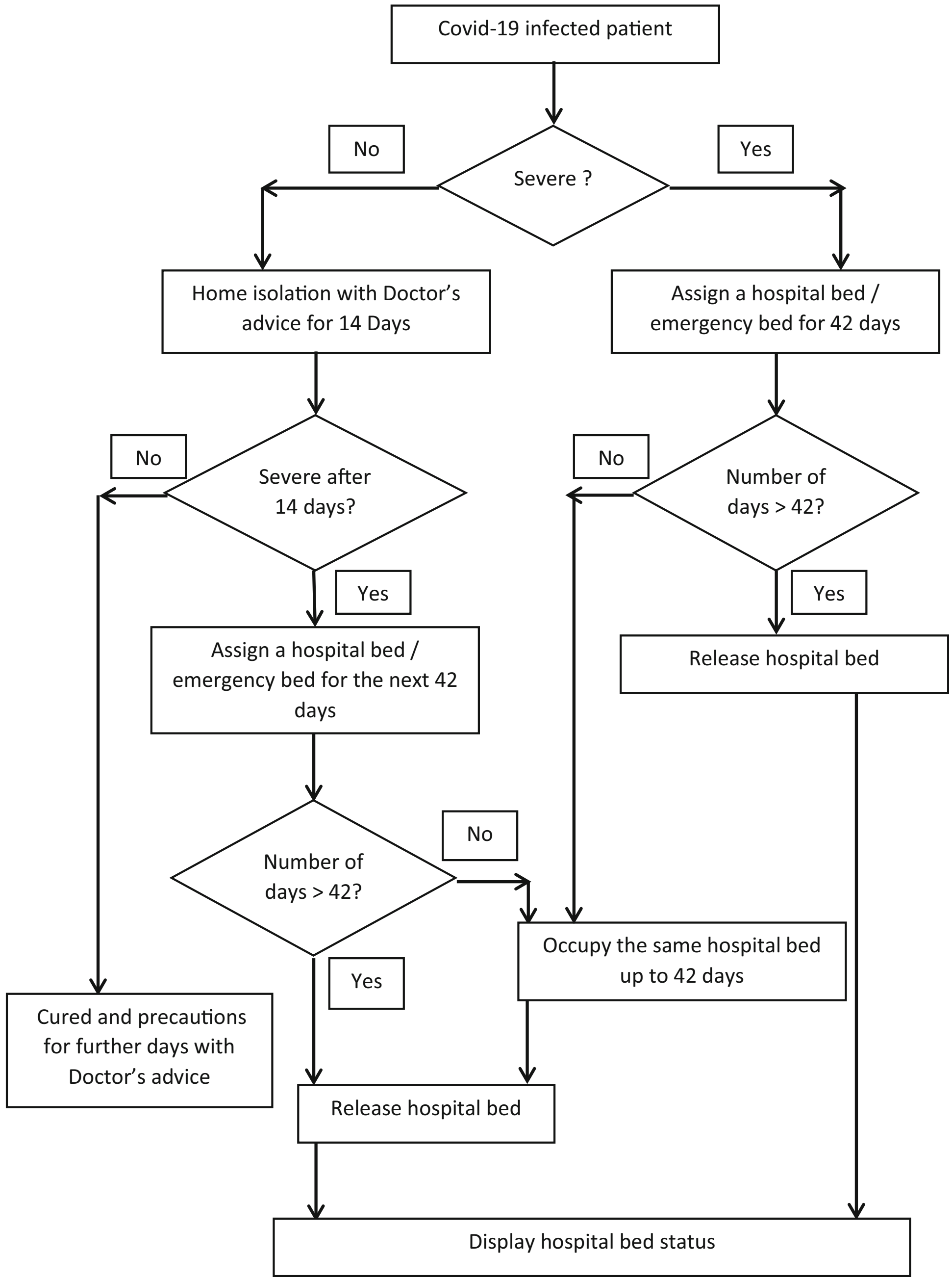


Fig. 1 Proposed methodology

in Tables 2 and 3. Graphically, it can be represented as shown in Fig. 2. Our main objective is to show the hospital beds as well as emergency beds requirement by considering the number of active cases as on July 26, 2020, by applying the proposed method and to compare with FCFS-based method.

As per the report, out of total COVID-19 infected cases, 20% of cases are severe. Hence, from Tables 2 and 3, we

Table 2 Week-wise COVID-19 data in India from 2nd February 2020 to 10th May 2020

Patient Status	Feb. 2	Feb. 9	Feb. 16	Feb. 23	Mar. 1	Mar. 8	Mar. 15	Mar. 22	Mar. 29	Apr. 5	Apr. 12	Apr. 19	Apr. 26	May 3	May 10
Confirmed	2	3	3	3	3	39	113	403	1139	4293	9211	17,305	27,890	42,779	67,177
Recovered	0	0	2	3	3	3	13	23	102	329	1086	2854	6523	11,763	20,970
Dead	0	0	0	0	0	0	2	7	27	118	332	560	881	1463	2214
Active	2	3	1	0	0	36	98	373	1010	3843	7790	13,888	20,483	29,549	43,989

Table 3 Week-wise COVID-19 data in India from 17th May 2020 to 26th July 2020

Patient Status	May 17	May 24	May 31	Jun. 7	Jun. 14	Jun. 21	Jun. 28	July 5	July 12	July 19	July 26
Confirmed	95,699	138,536	190,648	257,481	333,038	426,901	549,197	697,846	879,467	1,118,107	1,436,006
Recovered	36,795	57,694	91,862	123,848	169,684	237,258	321,777	424,894	554,429	700,500	918,745
Dead	3025	4024	5405	7205	9521	13,703	16,487	19,701	23,182	27,493	32,812
Active	55,875	76,809	93,368	126,412	153,792	175,889	210,877	253,168	301,471	389,707	484,041

can consider that total confirmed cases are 1,436,006 in India up to July 26, 2020, out of which 918,745 infected patients are recovered and 32,812 are dead. Here, total active cases are 484,041 out of which around 96,808 cases are severe and 387,233 cases are mild by considering 20% severe cases and 80% mild cases. As per the proposed work, 96,808 number of hospital beds are required immediately for the treatment of 96,808 number of severe cases. Again, we have considered that around 10% of mild cases will be changed to severe cases. Hence, 38,723 cases will be changed from mild cases to severe cases for which additional 38,723 beds are required for treatment of such cases. So, the minimum number of hospital bed requirement is 135,531 out of 484,041 active cases. If we normalize the total active cases to 1000, then the minimum number of bed requirement is approximately 280 by applying the proposed approach. If we apply the FCFS-based approach, then the minimum number of bed requirement is much more than 280 for the treatment of these patients in this scenario which is very difficult to manage.

4 Results and discussion

The simulation of the proposed work is carried out using MATLAB R2015b [61]. From the analysis of Tables 2, 3 and Fig. 2 by using the proposed approach, a minimum of 280 beds is required for 1000 number of infected patients (active cases) in the worst-case scenario. So, if 1000 active cases are normalized to 10 active cases, then the minimum number of bed requirement is 2.8. 2.8 can be considered as

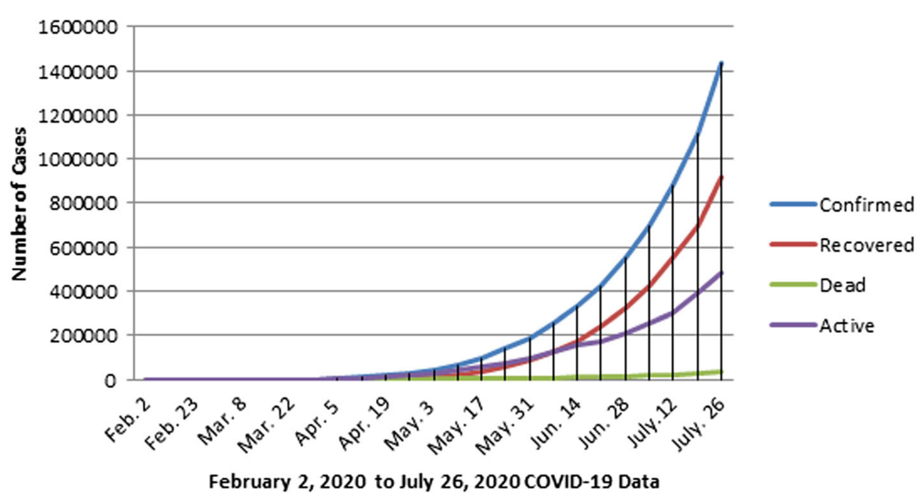


Fig. 2 Confirmed, recovered, dead and active cases in India from 2nd February 2020 to 26th July 2020

either 2 or 3. In our work, we have analyzed the status of the number of bed requirement by considering 2 and 3 beds, 4 and 6 beds, 6 and 9 beds, 8 and 12 beds separately for 10, 20, 30 and 40 active cases, respectively, by applying normalization mechanism. As 80% of cases are mild and 20% cases are severe, so out of 10 active cases 8 can be considered as mild cases and 2 can be considered as severe cases. Similarly, out of 20 active cases, 16 can be considered as mild cases and 4 can be considered as severe cases. Again, out of 30 active cases, 24 can be considered as mild cases and 6 can be considered as severe cases, and out of 40 active cases, 32 can be considered as mild cases and 8 can be considered as severe cases. As we have assumed that 10% of cases are death cases, so out of 10, 20, 30 and 40 active cases, the death cases will be 1, 2, 3 and 4, respectively. Again, we have assumed that 10% mild cases will be changed to severe cases although almost all the mild cases have recovered. So, out of 10, 20, 30 and 40 active cases, change from mild to severe cases will be 1, 2, 3 and 4, respectively. The proposed method is analyzed using 10, 20, 30 and 40 cases separately and compared with the FCFS-based method.

By referring to Eqs. 1, 2 and 3, we assume that out of 10 active cases, the patients with mild cases are represented as M1, M2, M3, M4, M5, M6, M7 and M8 and the patients with severe cases are represented as S1 and S2. We have assigned randomly the probability of 0.2, 0.8, 0.8, 0.8, 0.8, 0.8, 0.8 and 0.8 to M1, M2, M3, M4, M5, M6, M7 and M8, respectively, and the probability of 0.2 and 0.8 to S1 and S2, respectively. We have also assigned that in each week two number of active cases will arise up to first five weeks by using uniform distribution mechanism and these two cases may be mild or severe or any combination of mild and severe cases. By using this concept, we have analyzed 76 cases by applying the proposed approach for 10 number of active cases by considering 2 hospital beds such as B1, B2 and 3 hospital beds such as B1, B2, B3 separately and compared with FCFS-based approach. These 10 numbers of active cases will be normalized to any number of active cases to describe the assignment of hospital beds and emergency beds to the COVID-19 infected patients. In this work, we have mainly focused on the assignment of hospital beds and emergency beds to the COVID-19 infected patients by considering the total number of active cases as on July 26, 2020. Here, the hospital beds are represented as B1, B2, B3, …., Bm and the emergency beds are represented as E1, E2, E3, …., En. Here, m and n represent the number of hospital beds and emergency beds, respectively. Some of the cases are described by applying Algorithms 1 and 2 as follows.

Case 1.1: (Proposed approach: 10 active cases with 2 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	S1, S2	S1, S2	Assign B1, B2 to S1, S2, respectively, for 42 days	–	0	0
Week 2	M1, M2	S1, S2, M1, M2	M1, M2: Home isolation with doctor's advice for 14 days	–	0	0
Week 3	M3, M4	S1, S2, M1, M2, M3, M4	M3, M4: Home isolation with doctor's advice for 14 days	–	0	0
Week 4	M5, M6	S1, S2, M1, M3, M4, M5, M6	M5, M6: Home isolation with doctor's advice for 14 days M1: Mild changed to severe and assign E1 for the next 42 days	M2: cured	0	1 (E1)
Week 5	M7, M8	S1, S2, M1, M5, M6, M7, M8	M7, M8: Home isolation with doctor's advice for 14 days	M3, M4: Cured	0	0
Week 6	–	S1, S2, M1, M7, M8	–	M5, M6: Cured	0	0
Week 7	–	M1	Assign B1 to M1 for next 21 days E1: Removed	S2, M7, M8: Cured S1: Dead	1 (B2)	0
Week 8	–	M1	–	–	1(B2)	0
Week 9	–	M1	–	–	1(B2)	0
Week 10	–	–	–	M1: Cured	2(B1, B2)	0

Total number of emergency bed required = 1

Case 1.2: (FCFS-based approach: 10 active cases with 2 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	S1, S2	S1, S2	Assign B1, B2 to S1, S2, respectively, for 42 days	–	0	0
Week 2	M1, M2	S1, S2, M1, M2	Assign E1, E2 to M1, M2, respectively, for 14 days	–	0	2 (E1, E2)
Week 3	M3, M4	S1, S2, M1, M2, M3, M4	Assign E3, E4 to M3, M4, respectively, for 14 days	–	0	2 (E3, E4)
Week 4	M5, M6	S1, S2, M1, M3, M4, M5, M6	Assign E2, E5 to M5, M6 respectively for 14 days: M1: Mild changed to severe and occupy the same E1 for the next 42 days	M2: Cured	0	1 (E5)
Week 5	M7, M8	S1, S2, M1, M5, M6, M7, M8	Assign E3, E4 to M7, M8, respectively, for 14 days	M3, M4: Cured	0	0
Week 6	–	S1, S2, M1, M7, M8	E2, E5: Removed	M5, M6: Cured	0	0
Week 7	–	M1	E1, E3, E4: Removed Assign B1 to M1 for the next 14 days	S2, M7, M8: Cured S1: Dead	1 (B2)	0
Week 8	–	M1	–	–	1(B2)	0
Week 9	–	M1	–	–	1(B2)	0
Week 10	–	–	M1: Cured	–	2 (B1, B2)	0

Total number of emergency bed required = 5

Case 1.3: (Proposed approach: 10 active cases with 3 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	S1, S2	S1, S2	Assign B1, B2 to S1, S2, respectively, for 42 days	–	1 (B3)	0
Week 2	M1, M2	S1, S2, M1, M2	M1, M2: Home isolation with doctor's advice for 14 days	–	1 (B3)	0
Week 3	M3, M4	S1, S2, M1, M2, M3, M4	M3, M4: Home isolation with doctor's advice for 14 days	–	1 (B3)	0
Week 4	M5, M6	S1, S2, M1, M3, M4, M5, M6	M5, M6: Home isolation with doctor's advice for 14 days M1: Mild changed to severe and assign B3 for the next 42 days	M2: Cured	0	0
Week 5	M7, M8	S1, S2, M1, M5, M6, M7, M8	M7, M8: Home isolation with doctor's advice for 14 days	M3, M4: Cured	0	0
Week 6	–	S1, S2, M1, M7, M8	–	M5, M6: Cured	0	0
Week 7	–	M1	–	S2, M7, M8: Cured S1: Dead	2 (B1, B2)	0
Week 8	–	M1	–	–	2 (B1, B2)	0
Week 9	–	M1	–	–	2 (B1, B2)	0
Week 10	–	–		M1: Cured	3 (B1, B2, B3)	0

Total number of emergency bed required = 0

Case 1.4: (FCFS-based approach: 10 active cases with 3 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	S1, S2	S1, S2	Assign B1, B2 to S1, S2, respectively, for 42 days	–	1 (B3)	0
Week 2	M1, M2	S1, S2, M1, M2	M1, M2: Assign B3 to M1 and E1 to M2 for 14 days	–	0	1 (E1)
Week 3	M3, M4	S1, S2, M1, M2, M3, M4	Assign E2, E3 to M3, M4, respectively, for 14 days	–	0	2 (E2, E3)
Week 4	M5, M6	S1, S2, M1, M3, M4, M5, M6	Assign E1, E4 to M5, M6, respectively, for 14 days M1: Mild changed to severe and occupy the same B3 for the next 42 days	M2: Cured	0	1(E4)
Week 5	M7, M8	S1, S2, M1, M5, M6, M7, M8	Assign E2, E3 to M7, M8, respectively, for 14 days	M3, M4: Cured	0	0
Week 6	–	S1, S2, M1, M7, M8	E1, E4: Removed	M5, M6: Cured	0	0
Week 7	–	M1	E2, E3: Removed	S2, M7, M8: Cured S1: Dead	2 (B1, B2)	0
Week 8	–	M1	–	–	2 (B1, B2)	0
Week 9	–	M1	–	–	2 (B1, B2)	0
Week 10	–	–		M1: cured	3 (B1, B2, B3)	0

Total number of emergency bed required = 4

Case 2.1: (Proposed approach: 10 active cases with 2 beds)

sWeek	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	M1, M2	M1, M2	M1, M2: Home isolation with doctor's advice for 14 days	–	2 (B1, B2)	0
Week 2	M3, M4	M1, M2, M3, M4	M3, M4: Home isolation with doctor's advice for 14 days	–	2 (B1, B2)	0
Week 3	M5, M6	M1, M3, M4, M5, M6	M5, M6: Home isolation with doctor's advice for 14 days M1: Mild changed to severe and assign B1 for the next 42 days	M2: Cured	1 (B2)	0
Week 4	M7, M8	M1, M5, M6, M7, M8	M7, M8: Home isolation with doctor's advice for 14 days	M3, M4: Cured	1 (B2)	0
Week 5	S1, S2	M1, M7, M8, S1, S2	Assign bed B2 to S1 and assign E1 to S2 for 42 days	M5, M6: Cured	0	1(E1)
Week 6	–	M1, S1, S2	–	M7, M8: Cured	0	0
Week 7	–	M1, S1, S2	–	–	0	0
Week 8	–	M1, S1, S2	–		0	0
Week 9	–	S1, S2	E1: Removed Assign B1 to S2 for the next the 14 days	M1: Cured	0	0
Week 10	–	S1, S2	–		0	0
Week 11	–	–	–	S1: Dead S2: Cured	2 (B1, B2)	0

Total number of emergency bed required = 1

Case 2.2: (FCFS-based approach: 10 active cases with 2 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	M1, M2	M1, M2	Assign B1, B2 to M1, M2, respectively, for 14 days	–	0	0
Week 2	M3, M4	M1, M2, M3, M4	Assign E1, E2 to M3, M4, respectively, for 14 days	–	0	2 (E1, E2)
Week 3	M5, M6	M1, M3, M4, M5, M6	M1: Mild changed to severe and occupy the same B1 for the next 42 days Assign B2, E3 to M5, M6, respectively, for 14 days	M2: Cured	0	1 (E3)
Week 4	M7, M8	M1, M5, M6, M7, M8	Assign E1, E2 to M7, M8, respectively, for 14 days	M3, M4: Cured	0	0
Week 5	S1, S2	M1, M7, M8, S1, S2	Assign bed B2 to S1 and E3 to S2 for 42 days	M5, M6: Cured	0	0
Week 6	–	M1, S1, S2	E1, E2: Removed	M7, M8: Cured	0	0
Week 7	–	M1, S1, S2	–		0	0
Week 8	–	M1, S1, S2	–		0	0
Week 9	–	S1, S2	Assign B1 to S2 and E3 to S2 for next 14 days E3: Removed	M1: Cured	0	0
Week 10	–	S1, S2	–	–	0	0
Week 11	–	–	–	S1: Dead S2: Cured	2 (B1, B2)	0

Total number of emergency bed required = 3

Case 2.3: (Proposed approach: 10 active cases with 3 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	M1, M2	M1, M2	M1, M2: Home isolation with doctor's advice for 14 days	–	3 (B1, B2, B3)	0
Week 2	M3, M4	M1, M2, M3, M4	M3, M4: Home isolation with doctor's advice for 14 days	–	3 (B1, B2, B3)	0
Week 3	M5, M6	M1, M3, M4, M5, M6	M1: Mild changed to severe and assign bed B1 for the next 42 days M5, M6: Home isolation with doctor's advice for 14 days	M2: Cured	2 (B2, B3)	0
Week 4	M7, M8	M1, M5, M6, M7, M8	M7, M8: Home isolation with doctor's advice for 14 days	M3, M4: Cured	2 (B2, B3)	0
Week 5	S1, S2	M1, M5, M6, M7, M8, S1, S2	Assign B2, B3 to S1, S2, respectively, for 42 days	–	0	0
Week 6	–	M1, M7, M8, S1, S2	–	M5, M6: cured	0	0
Week 7	–	M1, S1, S2	–	M7, M8: cured	0	0
Week 8		M1, S1, S2	–	–	0	0
Week 9		S1, S2	–	M1: Cured	1 (B1)	0
Week 10		S1, S2	–	–	1 (B1)	0
Week 11		–	–	S1: Dead S2: Cured	3 (B1, B2, B3)	0

Total number of emergency bed required = 0

Case 2.4: (FCFS-based approach: 10 active cases with 3 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	M1, M2	M1, M2	Assign B1, B2 to M1, M2, respectively, for 14 days	–	1 (B3)	0
Week 2	M3, M4	M1, M2, M3, M4	M3, M4: Assign B3 to M3 and E1 to M4 for 14 days	–	0	1 (E1)
Week 3	M5, M6	M1, M3, M4, M5, M6	M1: Mild changed to severe and occupy the same B1 for the next 42 days Assign B2 to M5 and E2 to M6 for 14 days	M2: Cured	0	1 (E2)
Week 4	M7, M8	M1, M5, M6, M7, M8	Assign B3 to M7 and E1 to M8 for 14 days	M3, M4: Cured	0	0
Week 5	S1, S2	M1, M7, M8, S1, S2	Assign B2 to S1 and E2 to S2 for 14 days	M5, M6: Cured	0	0
Week 6	–	M1, S1, S2	Assign B3 to S2 for the next 35 days E1, E2: Removed	M7, M8: Cured	0	0
Week 7	–	M1, S1, S2	–	–	0	0
Week 8	–	M1, S1, S2	–	–	0	0
Week 9	–	S1, S2	–	M1: Cured	1 (B1)	0
Week 10	–	S1, S2	–	–	1 (B1)	0
Week 11	–	–	–	S1: Dead S2: Cured	3 (B1, B2, B3)	0

Total number of emergency bed required = 2

Case 3.1: (Proposed approach: 10 active cases with 2 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	S1, M2	S1, M2	Assign bed B1 to S1 for 42 days M2: Home isolation with doctor's advice for 14 days	–	1 (B2)	0
Week 2	M5, M6	S1, M2, M5, M6	M5, M6: Home isolation with doctor's advice for 14 days	–	1 (B2)	0
Week 3	S2, M3	S1, M5, M6, S2, M3	Assign bed B2 to S2 for 42 days M3: Home isolation with doctor's advice for 14 days	M2: Cured	0	0
Week 4	M7, M8	S1, S2, M3, M7, M8	M7, M8: Home isolation with doctor's advice for 14 days	M5, M6: Cured	0	0
Week 5	M1, M4	S1, S2, M7, M8, M1, M4	M1, M4: Home isolation with doctor's advice for 14 days	M3: Cured	0	0
Week 6	–	S1, S2, M1, M4	–	M7, M8: Cured	0	0
Week 7	–	S2, M1	M1: Mild changed to severe and assign B1 to M1 for the next 42 days	S1: Dead M4: Cured	0	0
Week 8	–	S2, M1	–	–	0	0
Week 9	–	M1		S2: Cured	1 (B2)	0
Week 10	–	M1	–	–	1 (B2)	0
Week 11	–	M1	–	–	1 (B2)	0
Week 12	–	M1	–	–	1 (B2)	0
Week 13	–	–		M1: Cured	2 (B1, B2)	0

Total number of emergency bed required = 0

Case 3.2: (FCFS-based approach: 10 active cases with 2 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	S1, M2	S1, M2	Assign bed B1 to S1 for 42 days and B2 to M2 for 14 days	–	0	0
Week 2	M5, M6	S1, M2, M5, M6	Assign E1 to M5 and E2 to M6 for 14 days	–	0	2 (E1, E2)
Week 3	S2, M3	S1, M5, M6, S2, M3	Assign bed B2 to S2 for 42 days and E3 to M3 for 14 days	M2: Cured	0	1 (E3)
Week 4	M7, M8	S1, S2, M3, M7, M8	Assign E1 to M7 and E2 to M8 for the next 14 days	M5, M6: Cured	0	0
Week 5	M1, M4	S1, S2, M7, M8, M1, M4	Assign E3 to M1 and E4 to M4 for 14 days	M3: Cured	0	1 (E4)
Week 6	–	S1, S2, M1, M4	E1, E2: Removed	M7, M8: Cured	0	0
Week 7	–	S2, M1	M1: Mild changed to severe and assign B1 to M1 for the next 42 days E3, E4: Removed	M4: Cured S1: Dead	0	0
Week 8	–	S2, M1	–	–	0	0
Week 9	–	M1	–	S2: Cured	1 (B2)	0
Week 10	–	M1	–	–	1 (B2)	0
Week 11	–	M1	–	–	1 (B2)	0
Week 12	–	M1	–	–	1 (B2)	0
Week 13	–	–	–	M1: Cured	2 (B1, B2)	0

Total number of emergency bed required = 4

Case 3.3: (Proposed approach: 10 active cases with 3 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	S1, M2	S1, M2	Assign bed B1 to S1 for 42 days M2: Home isolation with doctor's advice for 14 days	–	2 (B2, B3)	0
Week 2	M5, M6	S1, M2, M5, M6	M5, M6: Home isolation with doctor's advice for 14 days	–	2 (B2, B3)	0
Week 3	S2, M3	S1, M5, M6, S2, M3	Assign bed B2 to S2 for 42 days M3: Home isolation with doctor's advice for 14 days	M2: Cured	1 (B3)	0
Week 4	M7, M8	S1, S2, M3, M7, M8	M7, M8: Home isolation with doctor's advice for 14 days	M5,M6: Cured	1(B3)	0
Week 5	M1, M4	S1, S2, M7, M8, M1, M4	M1, M4: Home isolation with doctor's advice for 14 days	M3: Cured	1 (B3)	0
Week 6	–	S1, S2, M1, M4	–	M7, M8: Cured	1 (B3)	0
Week 7	–	S2, M1	M1: Mild changed to severe and assign bed B1 for the next 42 days	M4: Cured S1: Dead	1 (B3)	0
Week 8	–	S2, M1	–	–	1 (B3)	0
Week 9	–	M1	–	S2: Cured	2 (B2, B3)	0
Week 10	–	M1	–		2 (B2, B3)	0
Week 11	–	M1	–		2 (B2, B3)	0
Week 12	–	M1	–		2 (B2, B3)	0
Week 13	–	–	–	M1: Cured	3 (B1, B2, B3)	0

Total number of emergency bed required = 0

Case 3.4: (FCFS-based approach: 10 active cases with 3 beds)

Week	New case	Active case	Bed assignment	Cured/dead case	Number of bed left	Emergency bed requirement
Week 1	S1, M2	S1, M2	Assign B1 to S1 for 42 days and B2 to M2 for 14 days		1 (B3)	0
Week 2	M5, M6	S1, M2, M5, M6	Assign B3 to M5 and E1 to M6 for 14 days	–	0	1 (E1)
Week 3	S2, M3	S1, M5, M6, S2, M3	Assign B2 to S2 for 42 days and E2 to M3 for 14 days	M2: Cured	0	1 (E2)
Week 4	M7, M8	S1, S2, M3, M7, M8	Assign B3 to M7 and E1 to M8 for 14 days	M5, M6: Cured	0	0
Week 5	M1, M4	S1, S2, M7, M8, M1, M4	Assign E2 to M1 and E3 to M4 for 14 days	M3: Cured	0	1 (E3)
Week 6	–	S1, S2, M1, M4	Assign B3 to M1 for the next 7 days E1, E2: Removed	M7, M8: Cured	0	0
Week 7	–	S2, M1	M1: Mild changed to severe and occupy the same B3 for the next 42 days E3: Removed	M4: Cured S1: Dead	1 (B1)	0
Week 8	–	S2, M1	–	–	0	0
Week 9	–	M1		S2: Cured	2 (B1, B2)	0
Week 10	–	M1	–	–	2 (B1, B2)	0
Week 11	–	M1	–	–	2 (B1, B2)	0
Week 12	–	M1	–	–	2 (B1, B2)	0
Week 13	–	–	–	M1: Cured	3 (B1, B2, B3)	0

Total number of emergency bed required = 3

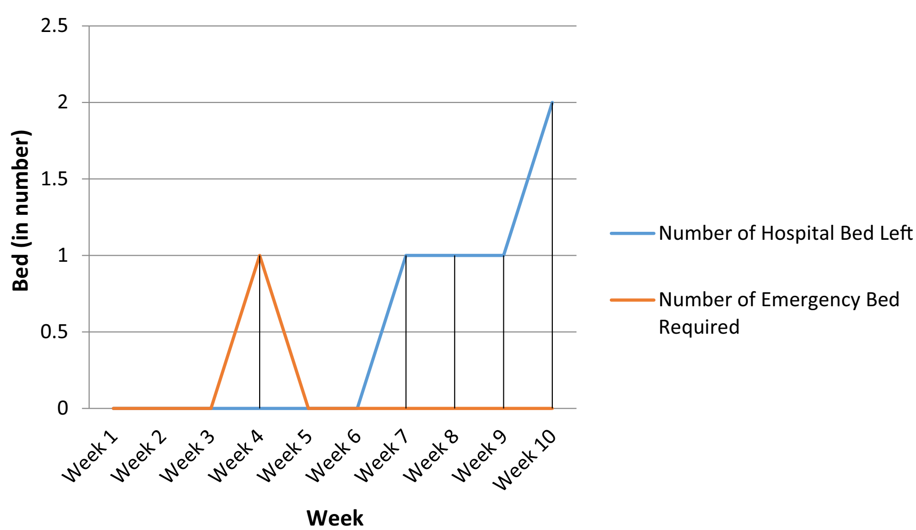


Fig. 3 Week-wise hospital bed status of case 1.1 using the proposed approach

We have analyzed 76 cases and out of 76 cases, the cases such as case-1.1, 1.2, 1.3, 1.4, case-2.1, 2.2, 2.3, 2.4, case-3.1, 3.2, 3.3, 3.4, 3.4 are taken randomly and analyzed by applying the proposed approach and FCFS-based approach where 2 and 3 number of available beds are considered separately for 10 number of active cases. The abovementioned cases are represented in Figs. 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13 and 14. This scenario is normalized by considering 20, 30, 40, 1000 and 484,041 number of active cases and we have calculated the number of emergency bed requirement apart from the number of available beds for each normalized case along with 10 active cases which are mentioned in Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15. From the analysis of above cases, Figs. 3, 4, 5, 6, 7, 8,

Fig. 4 Week-wise hospital bed status of case 1.2 using FCFS-based approach

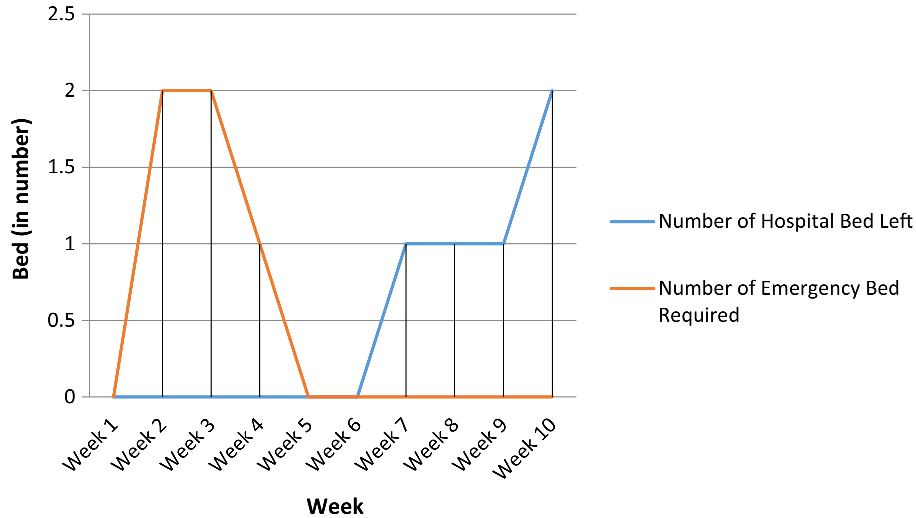


Fig. 5 Week-wise hospital bed status of case 1.3 using the proposed approach

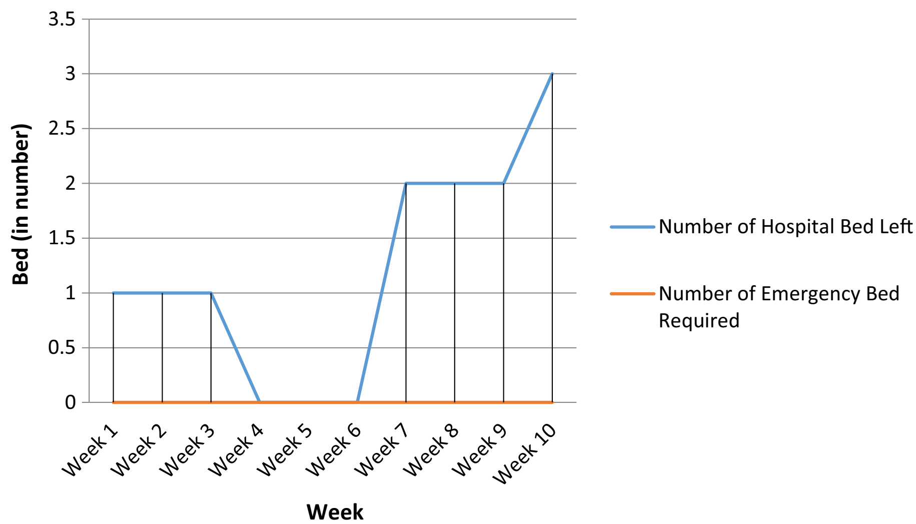
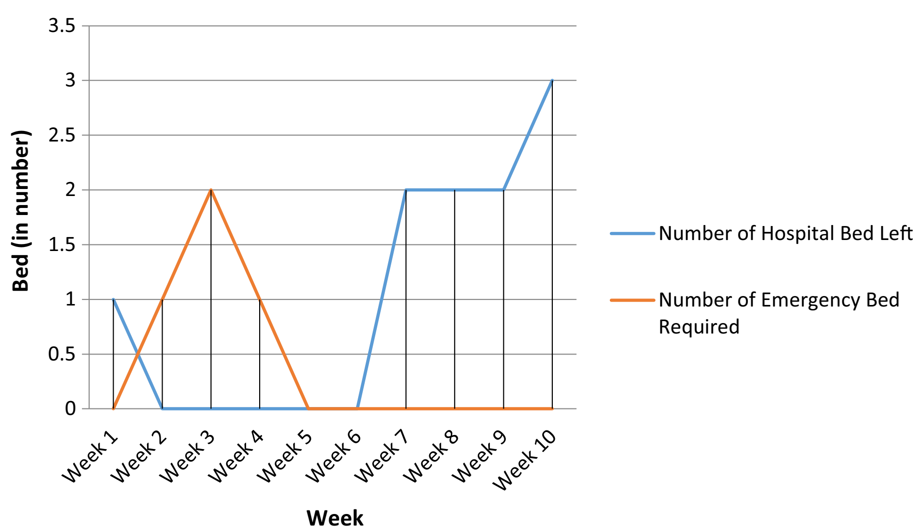


Fig. 6 Week-wise hospital bed status of case 1.4 using FCFS-based approach



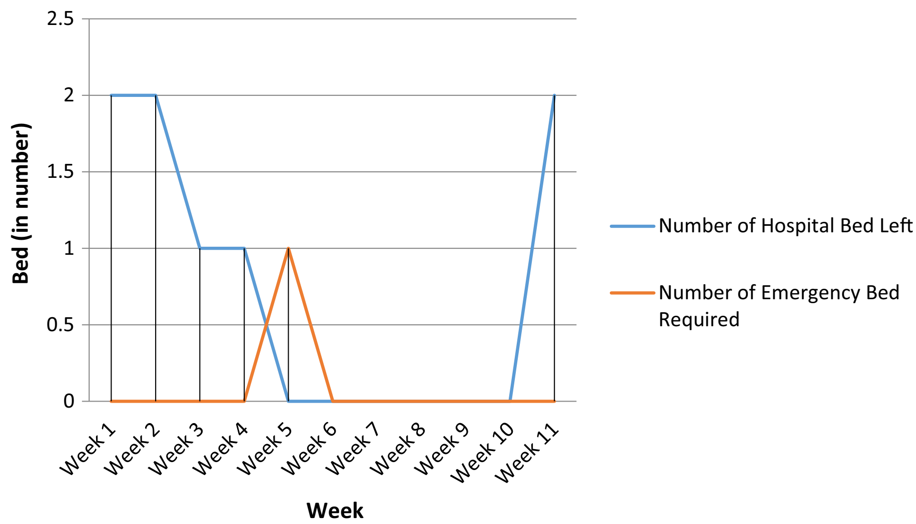


Fig. 7 Week-wise hospital bed status of case 2.1 using the proposed approach

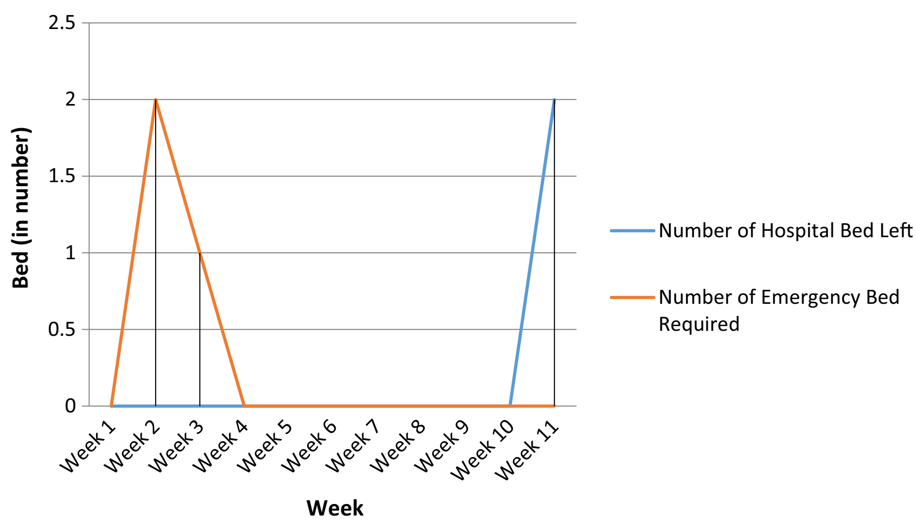


Fig. 8 Week-wise hospital bed status of case 2.2 using FCFS-based approach

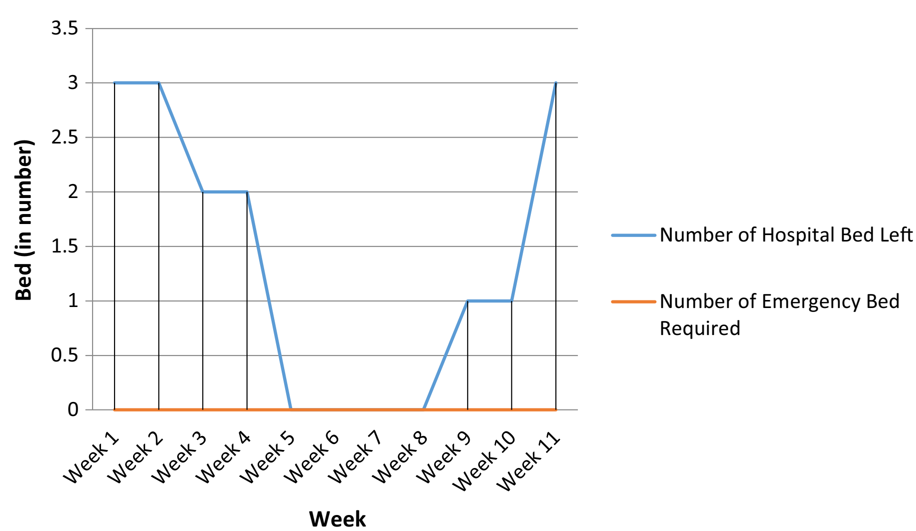


Fig. 9 Week-wise hospital bed status of case 2.3 using the proposed approach

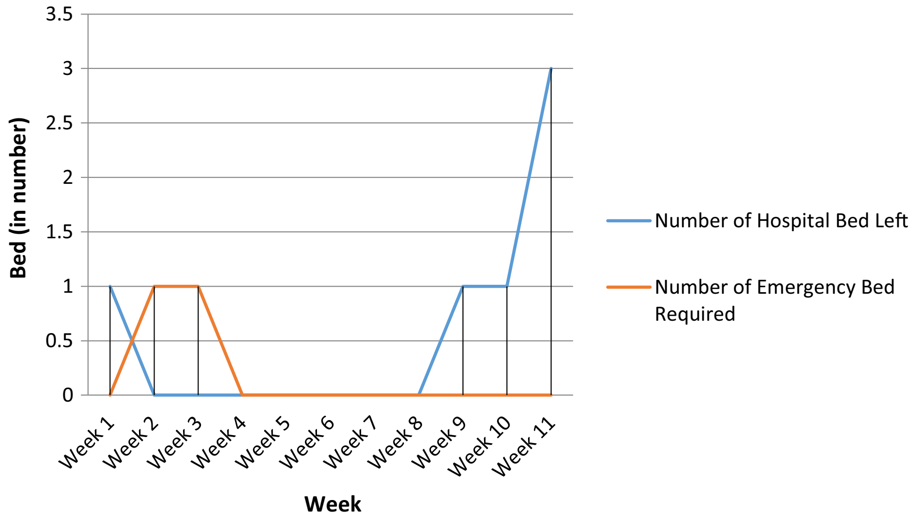


Fig. 10 Week-wise hospital bed status of case 2.4 using FCFS-based approach

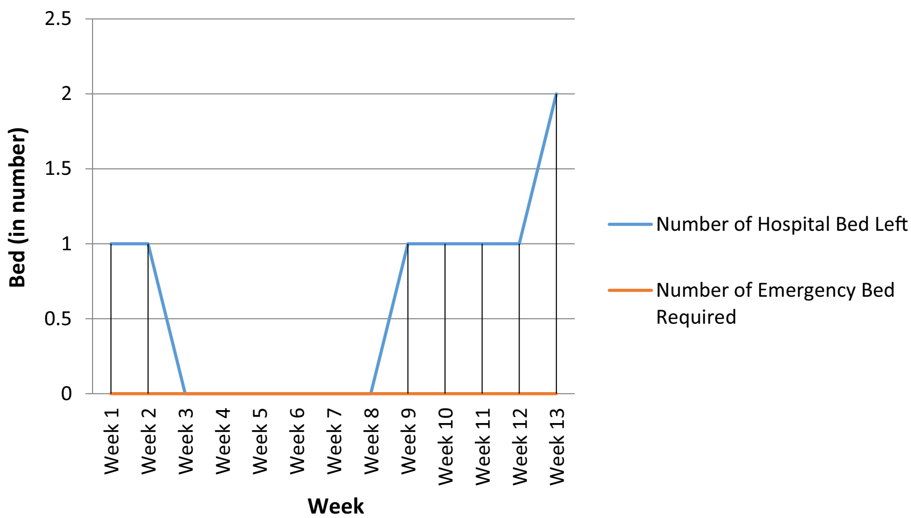


Fig. 11 Week-wise hospital bed status of case 3.1 using the proposed approach

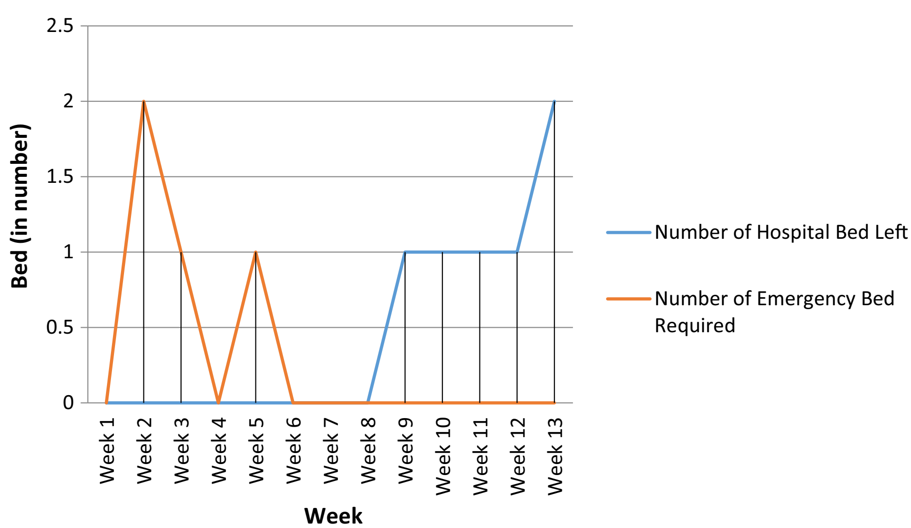


Fig. 12 Week-wise hospital bed status of case 3.2 using FCFS-based approach

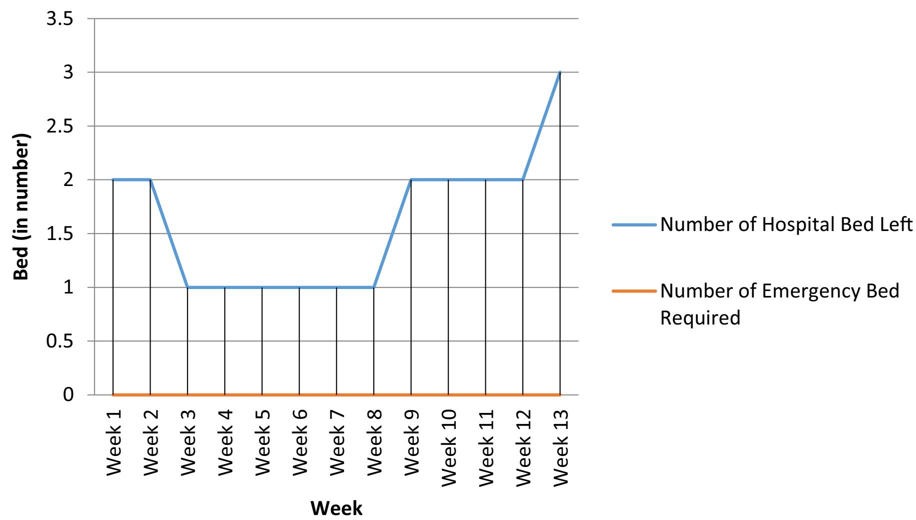


Fig. 13 Week-wise hospital bed status of case 3.3 using the proposed approach

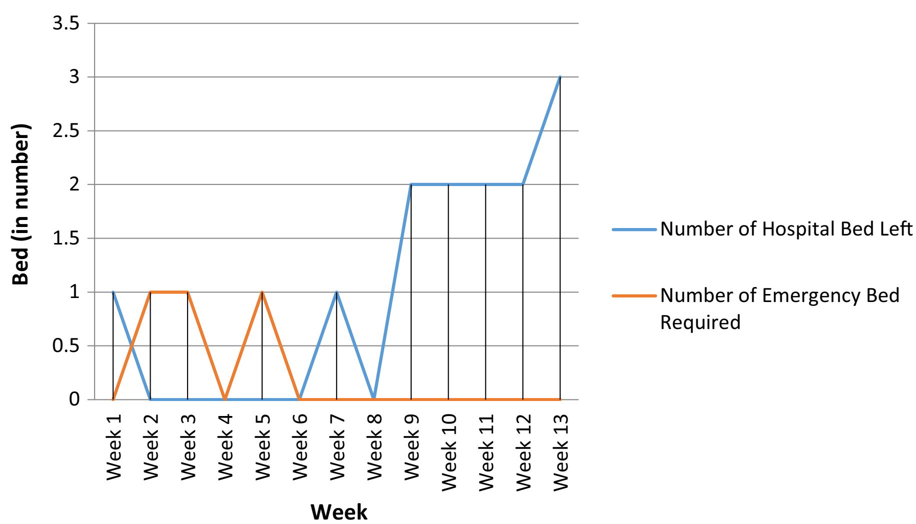


Fig. 14 Week-wise hospital bed status of case 3.4 using FCFS-based approach

9, 10, 11, 12, 13 and 14, and Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15, it is observed that the proposed approach can able to minimize the number of hospital emergency beds requirement as compared to FCFS-based approach in the worst-case scenario. The FCFS-based approach requires relatively more number of hospital beds and it creates challenging situations for the treatment of COVID-19 infected patients. The proposed approach can handle some cases with the available number of hospital beds without using any emergency beds for their treatment. From Tables 4 and 5, it is observed that when the number of active cases is 10 and number of available beds are 2, then from case-1.1, 1.2, the number of emergency bed requirements by using proposed approach is 1 and by using FCFS-based approach is 5, from case-2.1, 2.2, the number of emergency bed requirements by using proposed approach is 1 and by using FCFS-based approach is 3, from case-3.1, 3.2, the number of emergency bed requirements by using proposed approach is 0 and by using FCFS-based approach is 4. Similarly, when the number of active cases is 10 and number of available beds are 3, from case-1.3, 1.4, the number of emergency bed requirements by using proposed approach is 0 and by using FCFS-based approach is 4, from case-2.3, 2.4, the number of emergency bed requirements by using proposed approach is 0 and by using FCFS-based approach is 2, from case-3.3, 3.4, the number of emergency bed requirements by using proposed approach is 0 and by using FCFS-based approach is 3. Similarly, the emergency bed requirements for 20, 30, 40, 1000 and 484,041 active cases by using normalized mechanism are mentioned in Tables 6, 7, 8, 9, 10, 11, 12, 13, 14 and 15. Here, we have considered 484,041 active cases as the number of active cases in India was 484,041 as on July 26, 2020. By considering the scenario of 484,041

Table 4 Emergency bed requirement for 10 active cases with 2 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 10	1.1, 1.2	1	5
Hospital beds available = 2	2.1, 2.2	1	3
	3.1, 3.2	0	4

Table 5 Emergency bed requirement for 10 active cases with 3 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 10	1.3, 1.4	0	4
Hospital beds available = 3	2.3, 2.4	0	2
	3.3, 3.4	0	3

Table 6 Normalized emergency bed requirement for 20 active cases with 4 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 20	1.1, 1.2	2	10
Hospital beds available = 4	2.1, 2.2	2	6
	3.1, 3.2	0	8

Table 7 Normalized emergency bed requirement for 20 active cases with 6 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = s20	1.3, 1.4	0	8
Hospital beds available = 6	2.3, 2.4	0	4
	3.3, 3.4	0	6

Table 8 Normalized emergency bed requirement for 30 active cases with 6 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 30	1.1, 1.2	3	15
Hospital beds available = 6	2.1, 2.2	3	9
	3.1, 3.2	0	12

Table 9 Normalized emergency bed requirement for 30 active cases with 9 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 30	1.3, 1.4	0	12
Hospital beds available = 9	2.3, 2.4	0	6
	3.3, 3.4	0	9

active cases, the number of emergency beds requirement using proposed method as well as FCFS-based method are mentioned in Tables 14 and 15, and Figs. 15 and 16. So, the number of emergency beds requirement is very less by applying the proposed method as compared to FCFS-based method for the treatment of COVID-19 infected patients in the scenario of 484,041 active cases.

Table 10 Normalized emergency bed requirement for 40 active cases with 8 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 40	1.1, 1.2	4	20
Hospital beds available = 8	2.1, 2.2	4	12
	3.1, 3.2	0	16

Table 11 Normalized emergency bed requirement for 40 active cases with 12 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 40	1.3, 1.4	0	16
Hospital beds available = 12	2.3, 2.4	0	8
	3.3, 3.4	0	12

Table 12 Normalized emergency bed requirement for 1000 active cases with 200 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 1000	1.1, 1.2	100	500
Hospital beds available = 200	2.1, 2.2	100	300
	3.1, 3.2	0	400

Table 13 Normalized emergency bed requirement for 1000 active cases with 300 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 1000	1.3, 1.4	0	400
Hospital beds available = 300	2.3, 2.4	0	200
	3.3, 3.4	0	300

Table 14 Normalized emergency bed requirement for 484,041 active cases with 96,808 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 484,041	1.1, 1.2	48,404	242,021
Hospital beds available = 96,808	2.1, 2.2	48,404	145,212
	3.1, 3.2	0	193,616

Table 15 Normalized emergency bed requirement for 484,041 active cases with 145,212 available hospital beds

	Case reference	Number of emergency beds required	
		Proposed approach	FCFS-based approach
Number of active cases = 484,041	1.3, 1.4	0	193,616
Hospital beds available = 145,212	2.3, 2.4	0	96,808
	3.3, 3.4	0	145,212

5 Conclusion

This paper proposed a fuzzy rule-based approach using the priority-based method to assign hospital beds for the COVID-19 infected patients in the worst-case scenario where the number of hospital beds is very less as compared to the number of patients. This work focuses on the minimization of the number of hospital beds as well as emergency beds requirement in this critical situation. The proposed method is compared with the

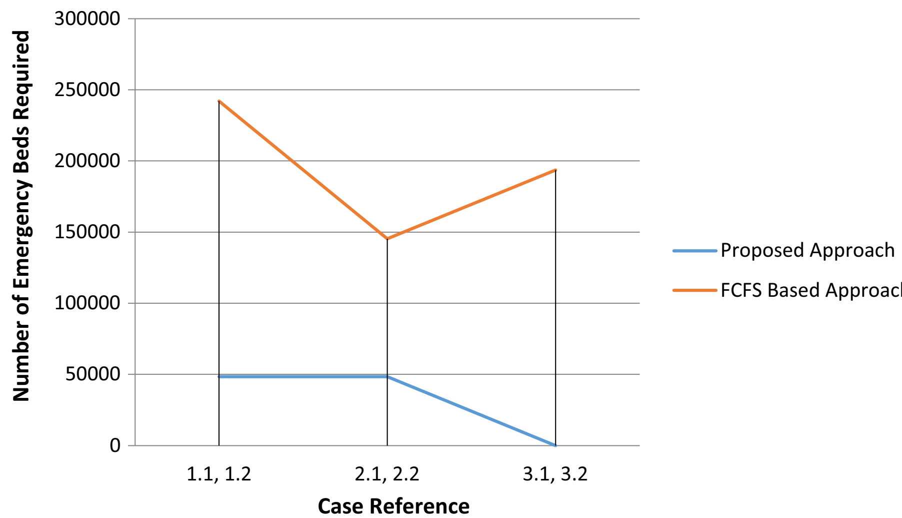


Fig. 15 Emergency bed requirement for 1010 active cases with 96,808 available hospital beds using normalized principle

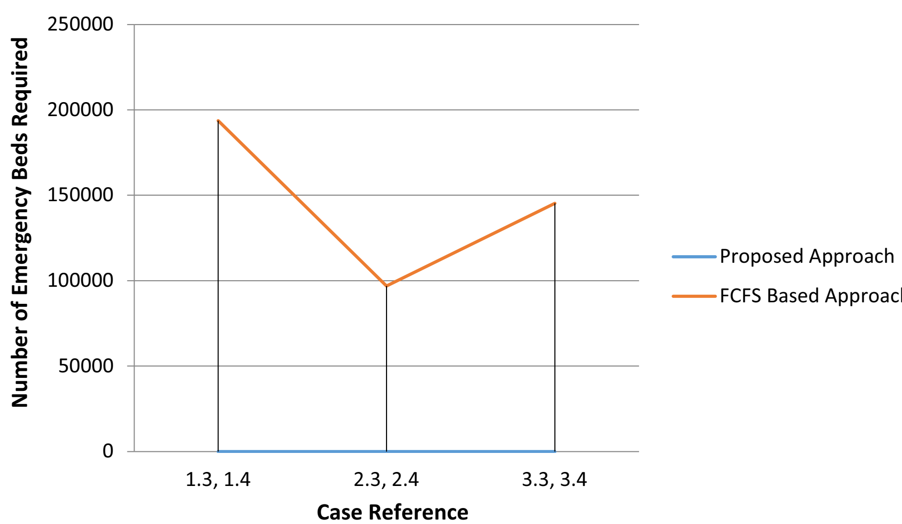


Fig. 16 Emergency bed requirement for 1010 active cases with 145,212 available hospital beds using the normalized principle

FCFS-based method by focusing on the number of hospital bed as well as the emergency bed assignment to the COVID-19 infected patients. From the results, it is concluded that the proposed method can handle this critical situation by assigning minimum the number of hospital beds and emergency beds to the COVID-19 infected patients as compared FCFS-based method. The proposed method is also able to handle some cases without assigning any emergency beds the COVID-19 infected patients. This approach can help the government of different countries as well as states to take initiatives accordingly for the assignment of hospital beds to the COVID-19 infected patients in a better way to increase their survival probability. This work will be extended to analyze several cases of hospital bed assignment to COVID19 infected patients by considering the scenarios where the number of positive cases will arise randomly in different weeks.

Compliance with ethical standards

Conflict of interest We have no conflicts of interest to disclose.

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