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A NOVEL SIMULATION-BASED TWO-STAGE OPTIMIZATION APPROACH FOR NURSE PLANNING

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Abstract
Maintaining the dynamism of the work scheduling of the nurses without causing them to lose their work motivation provides the sustainability of the effectiveness of health services. Thus, there is a need to develop patient-centred operational research approach applied to health services against new Covid19 waves or new pandemics. In this context, the aim of this study is to develop a novel simulation-based two-stage optimization approach to determine the required number of nurses and schedule the shifts of the nurse working in the Covid19 inpatient service in a Turkish State Hospital. We develop our model in three stages: 1) A simulation model is developed to specify the weekly required number of nurses and run for the scenarios based on demand increases and patient activity, 2) The first mathematical model is used to determine the weekly number of shifts, and 3) The second mathematical model is applied to prepare a fair nurse shift schedule in the pandemic service. This paper suggests a crucial study that will provide managers of healthcare services to plan ahead for personnel needs problems that may take place in the next waves of the Covid19 pandemic in advance.
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Key Words: Discrete Event Simulation, Mathematical Modelling, Optimization, Covid19, Nurse Scheduling, Capacity Planning

1. INTRODUCTION

Personnel scheduling involves the fair planning of employees regarding where and when they will perform their duties, under different constraints. Preparing personnel schedules is an extremely difficult task in some cases, especially for the service sector (i.e., healthcare), and it is necessary to pay attention to the work preferences of the personnel, leave days, working days on weekends and annual vacation periods while preparing the schedules. In healthcare organizations, staff scheduling becomes even more complicated, as it requires the availability of the necessary expertise and sufficient number of personnel to serve in order to meet patient needs as expected. The fact that the vast majority of personnel in healthcare services consists of nurses has made nurse scheduling problems popular over time. Nurse scheduling problems deal with how nurses should be assigned to shifts on a weekly or monthly basis by taking into account many constraints such as night shifts, day shifts, holidays, and legal obligations.

Many studies have been conducted in the literature on healthcare settings and scheduling problems, i.e., Buschiazzo et al. [1], Lee et al. [2] and Ordu et al. [3]. However, scheduling problems have become very difficult to sort out with the Covid19 epidemic while it is already complex in healthcare services which have to provide uninterrupted service 24/7. The pandemic has made many factors dynamic, especially the number of patients served, the number of intensive care beds, the number of health personnel, the number of service beds, and the number of intubated patients. In addition, the number of nurses might be also insufficient as the case is with all health personnel in hospitals operating at almost full capacity. Moreover, the available number of nurses may decrease even more at times since it is inevitable for healthcare personnel to be affected by the epidemic. Considering both physically and psychologically more difficult and intense working conditions along with all reasons mentioned above, scheduling the available nurses in a way that does not disrupt the service has become an extremely important and more complicated problem in the Covid19 pandemic.

In this study, we aim to develop a novel simulation-based two-stage optimization approach, which has not been developed yet, in order to better understanding the required number of nurses and enable a fair nurse shift schedule in Covid19 inpatient services. To do this, we develop a simulation model of a pandemic inpatient service in a Turkish State Hospital. After validating the model, we consider four cases studies and scenarios. Case studies are based on the weekly demand increases whereas scenarios are related to patient activities (i.e., inpatient admission rate, length of stay and transfer rate between departments). We obtain the weekly required number of nurses to embed in the first stage of the optimization model that is developed to determine weekly number of shifts. We then schedule the shifts of the nurses in the second stage of the optimization model.

The remaining of the paper is organized as follows: Section 2 gives the literature review. Section 3 explains the proposed simulation-optimization approach for the nurse scheduling problem in greater details. Section 4 discusses the results and Section 5 concludes the study, respectively.

2. LITERATURE REVIEW

Covid19 virus has adversely affected the world in many ways by threatening human life since the day that the pandemic has started. For this reason, researchers are constantly trying to develop new solutions to the problems experienced in every aspect. It is clear in the literature that the studies are spread over a wide area from production to service sector, case estimates to precautionary strategies, surgery planning to personnel schedules, which are affected by the Covid19 pandemic. For example, Ivanov [4] conducted a simulation study to observe and predict both the short and long-term effects of the epidemic on supply chains. Malkov [5] discussed the issue in terms of whether those who had Covid19 infection will be re-infected and conducted a simulation study under contagion and non-contamination scenarios. Kluger et al. [6] modelled the spread of SARS-CoV-2 in non-Covid19 services using Monte Carlo simulation. As a result, they stated that it would lead to less infection if the teams of nurses and doctors alternately stay in shifts for 3 days or longer. In addition, Gharakhanlou and Hooshangi [7], Currie et al. [8] and D'Orazio et al. [9] developed simulation models on strategies for the outbreak.

A number of studies has focussed on estimating the number of cases and hospital demands related to Covid19 pandemic. For example, Nuraini et al. [10] proposed a simple model to predict endemics in Indonesia. The model was based on similar data trends between Indonesia and South Korea. The results showed that the endemics will end in April 2020 when the total number of cases was more than 8000. Lu et al. [11] developed a simulation model to estimate the number of intensive care beds and the need for personal protective equipment. For this, they first built a data based SEIR model and integrated the prediction model into a discrete event simulation that modelled the interaction between patient flow and hospital resources. The model was verified with the data received from the hospital. After validating, the model was used to predict the bed usage in the future under a range of possible scenarios to advise on bed planning and stocking. Shoukat et al. [12] developed a computational model and simulation scenarios for Covid19 outbreak in each province in Canada. They demonstrated the upcoming challenges for the Canadian healthcare system and the potential role of self-isolation to decrease the demand for hospitals and ICUs.

In addition, a number of studies has been concentrated on efficient planning of hospital beds. For example, Güler and Geçici [13] developed a simulation model to support decision making regarding the short-term planning of hospital beds required for Covid19 in Spain. The simulation model focused on predicting the transient state of the health system. They used the Gompertz growth model and patient flow in the hospital, including possible admission to the ICU. The study estimated the number of ward and ICU beds required to provide health service to all patients in the following days.

Some researchers have been interested in staff schedules, shift planning by developing mathematical programming models and simulation models. For example, Lim et al. [14] dealt with a problem regarding hospital shift schedule during the Covid19 outbreak in Turkey. A mixed integer programming (MIP) model was proposed to address the shift planning. The developed model minimized physicians' exposure to the virus with a balanced workload in all departments. Gao et al. [15] developed a simulation model to investigate the effect of different staff combinations which included the number of staff on duty per shift, the number of shifts, and the total number of staff available to work in the laboratory. They emphasized the importance of monitoring personnel health, organizing a divided team, social distancing in the workplace, and the use of personal protective equipment by suggesting that laboratories should organize with the smaller teams and decrease the number of consecutive working days. Kuppuswamy and Sharma [16] investigated the experiences regarding shifts of nurses providing frontline care for patients infected with Covid19 in Shanghai and Wuhan. The data were analysed using Colaizzi's data analysis method. They obtained findings that will help to use the existing nurse workforce more efficiently by optimizing shift schedules. Zucchi et al. [17] carried out an extensive research on strategies to improve safety and quality of care, citing the lack of literature on efficient use of nurses during the Covid19 outbreak. Garcia-Vicuña et al. [18] addressed a real-life staff planning problem that emerged in a large Italian drug distribution warehouse in the context of the Covid19 outbreak. The challenge in the study was to build a program that tried to meet contractual working hours, taking into account the fact that employees must be separated by groups to decrease the risk of transmission. To overcome the problem, they proposed a mixed integer linear programming formulation (MILP). Tests were conducted on larger sized random samples to evaluate the scalability of the formulation. In addition, Guerriero and Guido [19] was interested in solving a flexible staff scheduling problem based on integer programming.

Staff organization during the Covid19 pandemic is identified as a major operational challenge in the literature [15]. Nurses are the primary healthcare human resources that play a key role in the management of Covid19 as there is not any specific treatment procedure and recovery largely depends on effective care [17]. In conclusion, there is a need to focus on the preparation of shift schedules of nurses struggling in the front lines of hospitals during the pandemic process by taking into account motivation of nurses and the situation nurses' PCR test results are positive or not. In the literature, the number of cases and staff scheduling issues have not been considered yet together. In addition, such this study aiming to meet the needs of Covid19 units on a weekly basis that the number of patients is variable and dynamic unlike other nurse scheduling problems in the literature has not yet been carried out. Unlike the studies concentrating on integrating simulation-optimization approach in the literature, we fill out this gap by integrating simulation and two-stage optimization model under different scenarios which are addressed according to the government policy and the course of the Covid19 case.

3. THE PROPOSED SIMULATION-OPTIMIZATION APPROACH FOR THE NURSE SCHEDULING PROBLEM

We propose a novel simulation-optimization approach (see Fig. 1) in order to schedule nurse working at a pandemic inpatient service at a state hospital in Turkey. Firstly, we develop a discrete event simulation model to capture the number of nurses which is required at the related department during the Covid19 pandemic. After that, two-stage mathematical model is developed. The first model enables the decision-makers to determine the weekly number of shifts for the department. The second model provides to specify the daily shift schedules. Then, we run the simulation model for the different what-if scenarios and determine the weekly number of shifts and daily shift schedules for nurses combating with the novel coronavirus for patients to win the struggle for survival.

The study has been carried out in a mid-size hospital in Turkey. The hospital serves patients with around 30 specialties (including the emergency department) and approximately 450 beds. In addition, it provides services to the community with a number of intensive care units (i.e., surgical intensive care and coronary intensive care) along with haemodialysis unit and home care services.

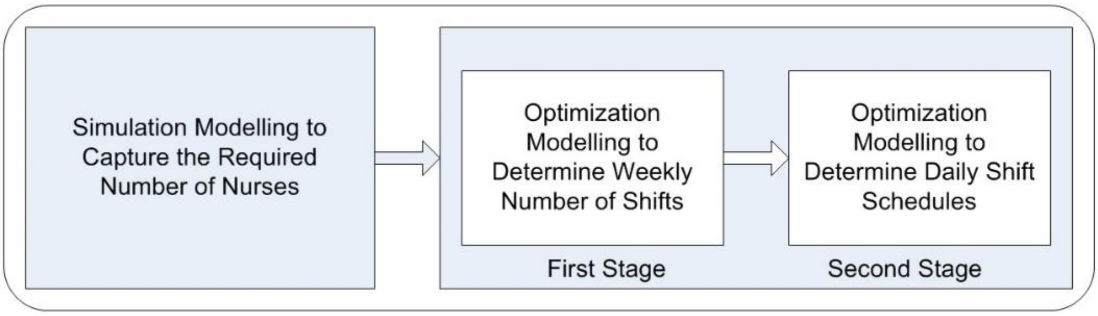

Figure 1: The structure of the proposed approach for nurses fighting with Covid19 at the inpatient service.

3.1 Simulation modelling

Fig. 2 illustrates the high-level conceptualized patient pathway of the simulation model. A patient arrives at the hospital by way of referrals (i.e., self-referrals, by ambulance, GP referrals or other referrals). After a receptionist process, patient waits for a nurse to take his/her medical history and perform a physical examination. After that, samples are taken from the patients for the Covid19 PCR test. Two different results are announced as a result of the PCR test. 1) The result is negative, and the patient is discharged. 2) The result is positive, and patient is either isolated at home depending on his/her health status and his/her treatment continues here, patient is admitted to the pandemic inpatient service or intensive care unit. During this treatment process, the patient who is in isolation at home might be admitted to the pandemic inpatient service or intensive care unit as a result of worsening of his/her symptoms. On the other hand, a patient hospitalized in the pandemic inpatient service is admitted to the intensive care unit if his/her symptoms worsen. Sample is taken from the patients for Covid19 PCR test again after completing treatment process. Treatment procedures continue in the related service/ICU if the test is positive. In case of the negative result, the patient is discharged. In another case, patient might be dead in the ICU. After conceptualizing the patient pathway, we developed a simulation model using Simul8 software.

We collected the required data from the hospital and the official sources published by Department of Health [20]. Table I presents the input parameters. Patient demand, number of beds, process times and length of stay are obtained from the hospital. However, we assume the statistical values of specific data (i.e., age and gender) are same with the data published by the Department of Health [20].

The conceptualized patient pathway has been verified by a number of health providers (i.e., nurses and doctors) working in the inpatient service and intensive care unit established to care patients who infected with Covid19 at the hospital. We have also used white box validation and black box validation methods. Using white box validation technique, the health providers have checked the simulation model is logically developed based on the real world. We have also used black box validation method to ensure the model produces results very close to the actual data at a 95 % significance level. We have determined optimum replication number as 20 replications using the fixed-sample-size procedure for the simulation model. In addition, the warm-up period is calculated as one month using the Welch's method.

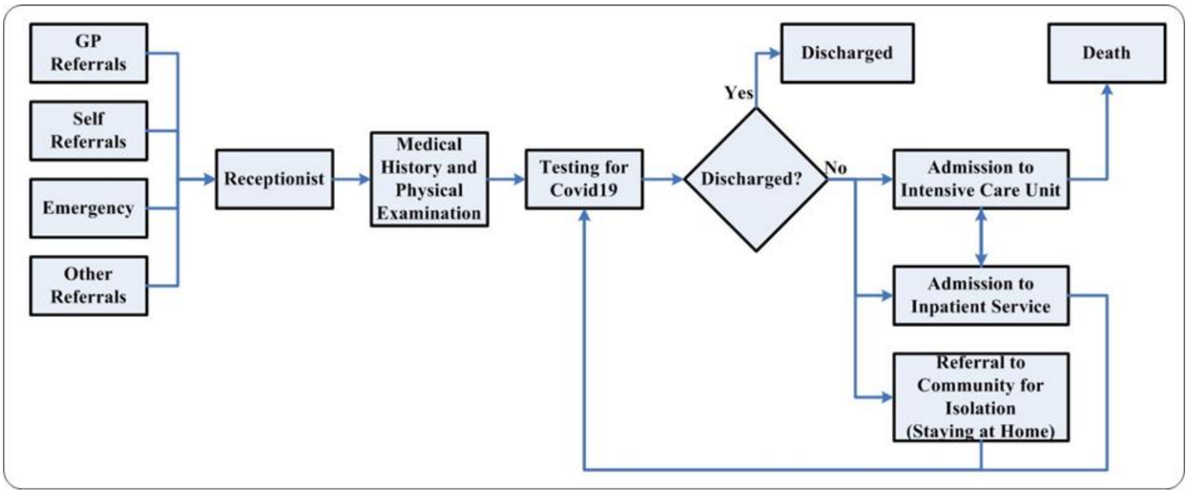

Figure 2: The high-level conceptualized patient pathway of the developed simulation model.

Table I: Input parameters of the simulation model.

Input Parameters	**Estimates**	**Distributions**	**References**
Patient demands	Frequency distribution	Frequency distribution	Local data
Age groups Age Group 1 (<2) Age Group 2 (2 – 4) Age Group 3 (5 – 14) Age Group 4 (15 – 24) Age Group 5 (25 – 49) Age Group 6 (50 – 64) Age Group 7 (65 – 79) Age Group 8 (80+)	 0.47 % 0.67 % 3.63 % 14.93 % 49.75 % 19.22 % 9.18 % 2.15 %	Multinomial	[20]
Number of beds 1. Inpatient Service 2. Intensive Care Unit	 100 21	Fixed	Local data
Length of stay Age Group 1 (<2) Age Group 2 (2 – 4) Age Group 3 (5 – 14) Age Group 4 (15 – 24) Age Group 5 (25 – 49) Age Group 6 (50 – 64) Age Group 7 (65 – 79) Age Group 8 (80+)	Frequency distribution	Frequency distribution	Local data
Gender 1. Male 2. Female	 49.37 % 50.63 %	Multinomial	[20]
Process times 1. Receptionist 2. Medical history and physical examination	 10 minutes 20 minutes	Average	Local data

In our study, we consider four different scenarios (see Table II) depending on the government policies explained below and the course of the pandemic in Turkey. In addition, a number of studies (i.e., Ordu et al. [3], Demir et al. [21]) on demand-capacity modelling of healthcare services in the literature has generally taken into account the percentage demand increases. Thus, case studies and scenarios have been determined as a result of the literature and the suggestions of the stakeholders (e.g., nurse, doctor). Therefore, four different case studies (see Table III) about the demand for the inpatient service have been also considered. The number of Covid19 cases in Turkey has gone up and experienced unfortunately record levels with the autumn and winter seasons. This situation causes the demand for the hospital in our study was assumed to increase, and it was foreseen that the number of cases would increase by 5 % each week. In addition, our first scenario includes the baseline model. The dramatic increases in cases have caused the government to issue a circular stating that people under 15 and over 65 should stay at home for most of the day. In this context, our second scenario assumes that the demand for the hospital in these age groups would decrease by 50 %. A number of reasons such as the increasing number of cases, and the mutation of the virus, and the increase in the demand of elderly people for healthcare services due to the winter season, and the negative impact of the virus in the elderly people can lead to an increase on the length of stay in hospital. In the third scenario, it is assumed that the length of stay in the pandemic inpatient ward will increase by 20 %. In addition, in case of the getting worse of the conditions of the patients infected with Covid19 in the inpatient service, the transfer rates from the inpatient service to the ICU can increase during this period. In the fourth scenario, we assume that there would be an increase of 10 % in the transfer rate. Our scenarios are considered cumulatively. That is, a scenario includes all the previous scenarios as well.

Table II: Case studies.

Case studies	Explanations
Case 1	Increasing demand by 5 % at Week 1
Case 2	Increasing demand by 5 % at Week 2
Case 3	Increasing demand by 5 % at Week 3
Case 4	Increasing demand by 5 % at Week 4

Table III: Scenarios in the study.

Scenarios	Change in	Increase / Decrease	Percentage of the changes
Scenario 1	Base model	No change	0 %
Scenario 2	Inpatient admissions rate for those less than or equals to 15 and over 65+	Decrease	50 %
Scenario 3	Length of stay in the inpatient service	Increase	20 %
Scenario 4	Transfer rate the inpatient service to the ICU	Increase	10 %

3.2 Two-stage mathematical modelling integrated with the simulation model

The required number of nurses per week obtained from the simulation model is embedded in our optimization model. Our optimization model consists of two stages. In the first stage optimization model, we focus on determining the weekly number of shifts under a number of constraints such as the maximum number of shifts a nurse will be able to have, the number of nurses on duty each week, and the total number of shifts a nurse will be assigned. In the second stage, the weekly number of shifts obtained in the first stage is used as input. In the second optimization model, a number of constraints such as the daily required number of nurses, and a nurse not being on duty on consecutive days are taken into account. Therefore, the optimum daily shifts needed in the inpatient service established for Covid19 pandemic is scheduled.

3.3 The first stage: determination of weekly number of shifts, parameters, decision variables, objective function and constraints

Our parameters and decision variables of the first stage mathematical model are defined as follows:

- i – The number of available nurses (1, 2, …, u)
- n – Weeks (1, 2, 3, 4)
- e – Number of shifts
- u – The total number of nurses
- C – The maximum weekly number of legal shifts per week
- E_{in} – The number of shifts that nurse *i* will have at the week *n*
- A_i – The number of excess shifts that nurse *i* had at the previous 4-week period
- M_n – The average number of shifts that to be hold at the week *n*
- RNN_n – The required number of nurse at the week *n* that is obtained from the simulation results

The first stage optimization model is given as follows:

$$M_n = \frac{\sum_{n=1}^{4}(\sum_{i=1}^{u} E_{in})}{u}, n \in (1, 2, 3, 4) \tag{1}$$

$$e_1 = \sum_{i=1}^{u}\sum_{n=1}^{4} |E_{in} - M_n| \tag{2}$$

$$e_2 = \sum_{n=1}^{4}\sum_{i=1}^{u-1} \left|E_{in} + A_i - (E_{(i+1)n} + A_{(i+1)})\right| \tag{3}$$

$$e_3 = \sum_{n=1}^{4}\sum_{i=1}^{u-1} \left|E_{in} - E_{(i+1)n}\right| \tag{4}$$

$$e_4 = \sum_{i=1}^{u}\sum_{n=1}^{3} \left|E_{in} - E_{i(n+1)}\right| \tag{5}$$

$$Min\, Z = e_1 + e_2 + e_3 + e_4 \tag{6}$$

Subject to:

$$RNN_n = \sum_{i=1}^{u} E_{in} \tag{7}$$

$$0 < E_{in} < C \text{ (If the nurse } i \text{ is on duty at the week } n) \tag{8}$$

$$E_{in} = 0 \text{ (If the nurse is not on duty at the week } n) \tag{9}$$

Eq. (1) averages the weekly number of shifts used in the objective function. Eqs. (2) to (5) balance the number of shifts the same nurse will hold each week, the total number of shifts, the number of shifts nurses will hold at the same week, and the weekly allocation of nurses among themselves, respectively. The objective function (6) minimizes the sum of these four objectives. Constraint (7) limits the number of nurses to be on weekly duty with the simulation data depending on the patient density. Constraint (8) determines the maximum number of nurses by taking into account the legal obligations and provides all variables must be positive integers. Constraint (9) ensures that the number of shifts that nurse *i* will have at the week *n* equals to zero in case of the nurse's PCR test result is positive.

3.4 The second stage: determination of daily shift schedules, parameters, decision variables, objective function and constraints

The second stage optimization model is presented as follows:

FE_i – The number of excessive weekend shifts the nurse *i* had at the previous 4-week period

NE_i – The number of weekend shifts the nurse will hold at the next 4-week period

k – Days (1, 2, 3,…, 28)

$$NE_i = \sum_{k=6}^{7} XE_{ik} + \sum_{k=13}^{14} XE_{ik} + \sum_{k=20}^{21} XE_{ik} + \sum_{k=27}^{28} XE_{ik}, \qquad i \in (1,2,\dots,u) \tag{10}$$

$$e_5 = \sum_{i=1}^{u-1} \left| FE_i + NE_i - FE_{(i+1)} + NE_{(i+1)} \right| \tag{11}$$

$$e_6 = \sum_{i=1}^{u} \sum_{k=1}^{27} \left| XE_{ik} - XE_{(k+1)} \right| \tag{12}$$

$$Min\ Z = e_5 + e_6 \tag{13}$$

$$E_{i1} = \sum_{k=1}^{7} XE_{ik}, i \in (1,2,\dots,u) \tag{14}$$

$$E_{i2} = \sum_{k=8}^{14} XE_{ik}, i \in (1,2,\dots,u) \tag{15}$$

$$E_{i3} = \sum_{k=15}^{21} XE_{ik}, i \in (1,2,\dots,u) \tag{16}$$

$$E_{i4} = \sum_{k=22}^{28} XE_{ik}, i \in (1,2,\dots,u) \tag{17}$$

$$\sum_{i=1}^{u} XE_{ik} = \frac{\sum_{i=1}^{u} E_{i1}}{7}, k \in (1,2,\dots,7) \tag{18}$$

$$\sum_{i=1}^{u} XE_{ik} = \frac{\sum_{i=1}^{u} E_{i2}}{7}, k \in (8,9,\dots,14) \tag{19}$$

$$\sum_{i=1}^{u} XE_{ik} = \frac{\sum_{i=1}^{u} E_{i3}}{7}, k \in (15,16,\dots,21) \tag{20}$$

$$\sum_{i=1}^{u} XE_{ik} = \frac{\sum_{i=1}^{u} E_{i4}}{7}, k \in (22,23,\dots,28) \tag{21}$$

$$XE_{ik} + XE_{i(k+1)} \leq 1 \tag{22}$$

$$XE_{ik} : \begin{cases} 1, & \text{The nurse } i \text{ is on duty at day } k \\ 0, & \text{Otherwise} \end{cases} \tag{23}$$

Eq. (11) balances the weekend shifts of the nurses. Eq. (12) ensures the nurses shifts are allocated evenly over the days. The objective function (13) minimizes the sum of these two objectives. Constraints (14) to (17) ensure that the inputs are compatible with the outputs from the previous stage, i.e., the weekly schedule. Constraints (18) to (21) limit the number of nurses who hold shift a day. Constraint (22) prevents nurses hold the shifts for two consecutive days. Constraint (23) determines that the nurse *i* will have a shift at day *k*.

4. RESULTS AND DISCUSSION

This study is developed to meet the needs of Covid19 units on a weekly basis that the number of patients is variable and dynamic unlike other nurse scheduling problems in the literature. Depending on the density of Covid19 patients in hospitals, the number of Covid19 units and accordingly number of nurses are increased and decreased. This dynamic situation is modelled with discrete event simulation and the results of the scenarios obtained are given in Table IV.

The two-stage mathematical model are developed by embedding the inputs obtained from the simulation modelling step and the data provided from a state hospital in Turkey. The mathematical models are solved using the GAMS program. The first stage mathematical model is used to determine the weekly required number of nurses. The results obtained for all scenarios are shown in Table V.

Table IV: Weekly required number of nurses (with the confidence interval values at 95 % significance level) obtained from the simulation modelling.

Scenarios	Case 1	Case 2	Case 3	Case 4
Scenario 1	10 (9, 10)	12 (11, 14)	16 (14, 18)	16 (14, 18)
Scenario 2	9 (8, 11)	12 (10, 14)	16 (14, 19)	12 (10, 14)
Scenario 3	10 (9, 12)	13 (12, 15)	18 (16, 21)	15 (13, 17)
Scenario 4	9 (8, 11)	13 (12, 15)	17 (15, 20)	13 (12, 15)

These outputs are used as inputs in scheduling the daily shift in the second stage of the mathematical modelling and the daily schedule for all scenarios is given in Table VI. The dynamic nature of the scheduling problem and the fact that it contains integer decision variables make the problem quite complex. However, considering the mathematical modelling in two stages significantly shorten the solution time of the problem. In this study, the first model reached the optimum result in 0.031 seconds, and the second model in 0.016 seconds.

In the model developed for Scenario 1, the required number of nurses (i) is 16 and the number of shifts in the first week (S_1) is 28. Due to legal obligations, the maximum number of shifts (E_{in}) a nurse will keep in a week is 4. Also, according to the simulation results, the number of shifts of the 11th and 12th nurses on the first week, and the 13th, 14th, 15th, and 16th nurses on the first and second week are zero.

Table V shows that the total number of shifts of nurses is balanced despite the weekly number of nurses is changed. 13th, 14th, 15th and 16th nurses have less shifts due to their participation in the unit starting from the 3rd week. In the Covid19 unit which is a very stressful, tiring, and risky environment, the first 10 nurses on duty from the first week have the opportunity to rest with fewer shifts, with the participation of 2 nurses in the 2nd week and 4 more nurses from the 3rd week. This situation provides a fair allocation to meet the demands of nurses in real life.

Table VI shows the 28-day shift schedule of the nurses working in the Covid19 unit. As seen in the table, the nurses' weekend shifts are evenly distributed. All of the nurses are on duty for 2 or 3 weekends. In addition, nurses do not stay on duty consecutively. The results obtained from the model fully meet our goals and constraints.

Table V: The required number of shifts for all scenarios.

Scenario 1																	
Order of weeks	Nurses																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1	3	4	4	2	2	2	2	3	3	3	-	-	-	-	-	-	28
2	3	2	2	4	2	2	3	3	3	3	4	4	-	-	-	-	35
3	2	2	2	2	2	3	3	2	2	2	3	3	3	3	4	4	42
4	2	2	2	2	3	3	2	2	2	2	3	3	4	4	3	3	42
Total	10	10	10	10	9	10	10	10	10	10	10	10	7	7	7	7	
Scenario 2																	
Order of weeks	Nurses																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1	3	3	4	3	3	3	3	3	3	-	-	-	-	-	-	-	28
2	3	3	3	3	2	3	3	3	3	3	3	3	-	-	-	-	35
3	2	2	2	2	3	2	2	3	3	4	4	4	4	4	4	4	49
4	3	3	2	3	3	3	3	3	3	3	3	3	3	3	4	3	48
Total	11	11	11	11	11	11	11	11	12	10	10	10	7	7	7	7	
Scenario 3																	
Order of weeks	Nurses																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1	3	3	3	3	2	3	3	3	3	2	-	-	-	-	-	-	28
2	3	3	3	2	2	2	2	2	2	3	4	3	4	-	-	-	35
3	2	2	2	2	3	2	2	2	2	2	3	3	3	4	3	4	41
4	2	2	2	2	3	2	3	3	3	3	3	4	3	3	4	-	42
Total	10	10	10	9	10	9	10	10	10	10	10	10	10	7	7	4	
Scenario 4																	
Order of weeks	Nurses																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Total
1	3	3	4	3	3	3	3	3	3		-	-	-	-	-	-	28
2	2	2	2	2	3	3	3	3	3	3	3	3	3	-	-	-	35
3	2	2	2	2	2	2	2	2	2	4	3	4	4	4	4	4	45
4	3	3	3	3	2	2	2	2	2	3	4	3	3	-	-	-	35
Total	10	10	11	10	10	10	10	10	10	10	10	10	10	4	4	4	

Table VI: The daily nurse schedule for Scenario 1.

Days	**Nurses**															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0
2	1	0	0	0	1	0	1	0	0	1	0	0	0	0	0	0
3	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0
4	1	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0
5	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0
6	0	0	0	1	0	0	1	0	1	1	0	0	0	0	0	0
7	1	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
8	0	0	0	1	0	0	0	0	1	1	1	1	0	0	0	0
9	1	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0
10	0	0	0	1	0	0	0	0	1	1	1	1	0	0	0	0
11	0	1	1	0	1	0	1	1	0	0	0	0	0	0	0	0
12	1	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0
13	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0
14	1	0	1	1	0	0	0	0	0	0	1	1	0	0	0	0
15	0	1	0	0	0	1	1	0	1	0	0	0	0	0	1	1

16	0	0	1	1	1	0	0	0	0	0	0	1	1	1	0	0
17	1	0	0	0	0	1	1	0	0	0	1	0	0	0	1	1
18	0	0	1	1	0	0	0	0	1	0	0	1	1	1	0	0
19	0	1	0	0	0	0	0	1	0	1	1	0	0	0	1	1
20	0	0	0	0	1	1	1	0	0	0	0	1	1	1	0	0
21	1	0	0	0	0	0	0	1	0	1	1	0	0	0	1	1
22	0	1	0	0	0	1	1	0	1	0	0	0	1	1	0	0
23	0	0	0	0	1	0	0	1	0	1	1	0	0	0	1	1
24	1	0	0	0	0	1	1	0	0	0	0	1	1	1	0	0
25	0	0	1	0	1	0	0	1	0	0	1	0	0	0	1	1
26	1	0	0	1	0	1	0	0	0	0	0	1	1	1	0	0
27	0	1	0	0	1	0	0	0	0	1	1	0	0	0	1	1
28	0	0	1	1	0	0	0	0	1	0	0	1	1	1	0	0

5. CONCLUSION

This study proposes a simulation-based two-stage mathematical modelling approach to optimize the number of nurses needed in hospitals despite the fluctuations in demand during the Covid19 pandemic. Balancing the total number of shifts as well as the number of shifts at the weekend among healthcare workers working in the hospital was a serious challenge and preparing the schedules by hand was time-consuming and laborious. The demand fluctuations observed in the hospital according to the course of the pandemic were captured by using the developed simulation model. Thus, the weekly required number of nurses was determined at a confidence interval of 95 %. Accordingly, the required number of shifts based on the demand and number of nurses in the hospital's inpatient service was specified. The second mathematical model produced the daily shift schedule. The results of this study show that a balanced scheduling between the nurses working in the Covid19 unit is achieved in a very short time with the proposed approach. In addition, a fair allocation of duties among nurses was ensured. Considering that the Covid19 pandemic is ongoing, we recommend that this study should be made available in practice for health institutions.

A limitation of the study is that the inability of nurses to work due to the pandemic was not taken into account. A number of constraints regarding this situation can be included in the mathematical models. In addition, this study prepared for the Covid19 pandemic can be also adapted for other epidemics that may occur in the future. Future research can be carried out by integrating two distinct methodologies (i.e., simulation and optimization) within a single modelling framework. Therefore, such user-friendly interfaces might allow the employees to run the health systems more easily and effectively.

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