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Nurse Scheduling Problem in Pandemic Situation: An Application in Ankara City Hospital

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Highlights

- Creation of a fair and balanced nurse scheduling.
- The first nurse scheduling study in Ankara City Hospital.
- Consideration of special situations and requests of nurses besides Covid-19 precautions.

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Abstract

With the Covid-19 epidemic, which first appeared in China in December 2019 and affected the world in a short time, the importance of health is increasing day by day. The increasing importance of health in combating he epidemic causes an increase in the need for hospitals and health personnel. The health personnel that have the main role in this struggle are nurses. When nurses are mentally and physically healthy, they are better equipped to serve and care for patients. In this study, a goal programming model has been developed in order to make November 2020 shift schedule of 50 nurses working in 4 clinics in Ankara City Hospital's General Hospital building. While developing the model; hospital rules, laws, Covid-19 measures were taken into consideration. In addition, extra precautions have been taken for the special conditions of nurses and for nurses who are in the high risk group for the transmission of the virus. The optimal result has been achieved by writing the developed model into the ILOG CPLEX Studio IDE program.

1. INTRODUCTION

In order to provide better service to the society, increase efficiency and ensure continuity, businesses must have sufficient personnel with appropriate knowledge and skills; must be assigned to the right place at the right time. Personnel scheduling used for assignment is used effectively in the production and service sectors [1]. When personnel scheduling studies conducted in the service sector are examined, the most important type of problem frequently included in the studies is nurse scheduling problems.

The Covid 19 epidemic, which affected the whole world in a short time, first appeared in Wuhan, China, in December 2019. In the fight against this virus, healthcare personnel who took part in the care of patients treated in hospitals constituted the most critical point of this process. For this reason, the World Health Organization declared the "World Nurses Year" to emphasize the importance of nurses in the epidemic [2].

Nurses; Healthcare personnel have the most important role as they are with the patients at all times throughout the treatment period. Nurses work in different polyclinics, different wards of health institutions and in designated shifts. Laws and regulations regarding the duties and responsibilities of nurses and their working conditions are determined by the state. Nurses must work weekdays and weekends in shifts determined by the hospital they work in and complete a maximum of 160 hours of work per month. While some hospitals work in 3 shifts, 8 hours a day, some hospitals work in two shifts, 8 hours and 16 hours a day. In addition to these shifts, there are also hospitals that work full-time shifts [3].

Nurse scheduling issues; ıt addresses the problem of how to allocate shifts to nurses, who are always needed in hospitals and have difficult and intense working conditions. With charts created using technological innovations; Negative factors affecting nurses are minimised by taking into account nurses' demands,

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restrictions and laws set by hospital management. In this way, maximum benefit can be achieved in terms of performance and efficiency [4].

In hospitals, nurse duty schedules are generally made manually on a weekly/monthly basis by the nurse in charge of each unit. However, due to differences or inequalities in nurses' shifts, these hours do not create a fair working environment.

In this study, the shift schedule of the nurses working in 4 clinics in Ankara City Hospital General Hospital (MH-1) block in November 2020 was discussed. In the early days of the Covid-19 epidemic, the hospital had two shifts, 08:00-16:00 and 16:00-08:00, and each nurse was working only in her own clinic. Due to the fact that the number of shifts was 2, the nurses were very tired and the shifts were combined due to the shortage of nurses in the clinics. Sometimes nurses could not even go home. In order to eliminate these problems, a 3-shift system was introduced as day (08.00-16.00), night (16.00-08.00), full-time (08.00-08.00), and now nurses other than the responsible nurses of the clinics are allowed to work in every clinic.

In the second part of this study, the nurse scheduling problem is included, in the third part, studies in the literature are included, in the fourth part goal programming is mentioned, in the fifth part the sample application is explained. Finally, in the sixth section, the results and recommendations of the application are explained.

When the scheduling studies in the literature are examined, it is seen that one of the most studied subjects in the health sector is nurse scheduling. Some studies on nurse scheduling in the literature are given below.

Miller et al., created a four-week schedule that aims to minimize the difference between the integer programming they use and the special demands of the nurses and the requests of the hospital administration [5]. Güngör developed a 0-1 integer programming model, which consists of two stages, aiming to minimize nurse costs. Determining the number of nurses required for shifts constituted the first stage of the model, and making two-week work plans of the determined nurses under certain restrictions constituted the second stage of the model [6]. Gutjahr and Rauner, for the first time, used the Ant Colony Optimization approach to solve the nurse scheduling problem. In addition to the working hours, days, shapes and qualifications of the nurses, they created a mathematical model taking into account both the hospital's preferences and the demands of the nurses and various loose and hard restrictions regarding costs [7]. Karaatlı and Güngör proposed a multi-objective fuzzy linear programming model to determine the best shifts for nurses to work more effectively according to the workload in the hospital. They then used a three-step heuristic assignment algorithm that allows nurses to assign shifts [8]. Bağ et al. first weighted the goals they determined for the solution of the nurse scheduling problem using the ANP method, and then they created a 0-1 integer programming model using the weights found. While creating the model, the factors affecting the nurses negatively were taken into account [9]. Öztürkoğlu and Çalışkan aimed to bring flexibility to nurses' starting hours with the integer mathematical programming model they established. In the model, it is aimed to ensure nurse satisfaction by taking into account the demands of [10]. Agyei et al., in a hospital in Ghana, developed a 0-1 integer goal programming model, which provides a balanced workload distribution among nurses and takes into account the wishes of nurses [11]. Sulak and Bayhan established a mathematical model for the scheduling problem of nurses working in the blood bank of an uninterrupted university hospital. While establishing the mathematical model, they aimed to make a balanced assignment by taking into account the shift hours of the hospital and the leave status of the nurses [12]. Aktürk et al. developed a goal programming model that aims to assign a total of thirteen nurses working in a state hospital in Kırıkkale to morning, evening, night and full-time shifts as balanced as possible [4]. Ang et al. tried to create a 1-year work plan for a group of 142,564 emergency service participants based on the performance criterion. In addition to legal restrictions and traditional rules, they proposed a multi-purpose mixed integer goal programming model, taking into account nurse-patient ratio, nurse preferences and leave days [13]. Karayel and Atmaca created a 0-1 integer mathematical programming model for a schedule that creates a fair and balanced assignment for nurses working in a private hospital and minimizes costs that provide the highest satisfaction for patients [14]. Varlı and Eren developed a goal programming model that meets the number of nurses needed in the emergency room, operating room and intensive care unit of a hospital in Kırıkkale [15]. Adoly et al. developed a mathematical model for nurse scheduling at a hospital in Egypt, based on a multi-network flow model. With this model, they aimed to provide a balanced distribution of the workload, to optimize the nurse demands and to reduce the overall cost of the hospital [16]. Zanda et

al. for the group of normal and specialist nurses, they created a goal programming model for the shift, nurse on call, and day off schedule, under the specific restrictions of the problem addressed [17]. Karpuz and Batun formulated the nurse scheduling and rescheduling problem in a private health center in Ankara as a two-stage stochastic program that minimizes the expected cost of rescheduling activities [18]. Taş and Çevik, a genetic algorithm was used to solve the weekly, 15-day and monthly scheduling problems of 15 nurses with 4 different restrictions. According to the results obtained, a balanced schedule in terms of time and labor was obtained by fulfilling all the restrictions of the nurse scheduling problem by using genetic algorithm [19]. Cürebal et al. carried out the assignment and scheduling studies of the personnel provided by the organization company for an event. They also took into account the Covid 19 precautions throughout the study. In this direction, it is aimed to assign the personnel with hereditary disorders to the duties where they will interact with the visitors the least [20]. Amindoust et al. proposed a new mathematical model for the scheduling problem for nurses working in three shifts, taking into account the fatigue factor. They developed a hybrid Genetic Algorithm (GA) for the solution of the proposed mathematical model. It was the first study to consider nurses' fatigue and to offer a program based on it [21]. Güler and Geçici addressed the problem of doctors scheduling shifts during Covid-19 in a hospital in Turkey. They proposed a mixed integer programming model to solve the shift scheduling problem and turn it into a decision support system (DSS). With the resulting charts, the possibility of exposure to the virus has been minimized by creating a balanced working environment for doctors [22]. Ariyani et al. addressed the problem of nurse scheduling for a private room prepared for the treatment of Covid-19 patients in a hospital. They had done the solution in Lingo 11.0 software by establishing a goal programming model to solve the problem. As a result of the solution, they found a 17-day schedule for the room and the minimum number of senior nurses and male nurses [23]. Küçük and Deveci Kocakoç found it by using genetic algorithm to find the most suitable working hours for 14 nurses working in the coronary intensive care unit of a hospital in Buca. The results obtained were compared with the actual shift schedules of the hospital [24].

This study differs from the classic nurse scheduling problem; it contributes to the literature by creating a schedule that takes into account the precautions taken during the epidemic, the wishes of the nurses and their specific situations, as it is carried out in the context of the Covid 19 epidemic. With this study, in order to reduce the negative effects of the Covid-19 epidemic on the health of nurses, pregnant nurses over the age of 50 and with the highest virus infection rate were not assigned to the Covid-19 Clinic. In addition, equal assignment was ensured by not combining shifts, preventing nurses from working uninterruptedly due to the high need for nurses due to the epidemic, allowing them to take leave for a sufficient period of time, and taking into account the nurses' special requests. With the schedule made, the right number of nurses was assigned to shifts and clinics in a balanced manner, providing a high level of health care for patients throughout the epidemic. Thus, the risk of transmitting the virus to nurses was minimized while ensuring the quality and continuity of service within the scope of the epidemic.

2. MATERIAL METHOD

The first goal programming study was conducted in 1955 by Charnes et al. carried out by Afterwards, Charnes and Cooper made studies in 1961 to develop goal programming [4].

Goal programming is a method often used in modeling problems with one or more objectives. The goal with this method is not to maximize or minimize the function; It is to minimize the deviation variables indicated by the symbols d_i^+ and d_i^- in the targets desired to be achieved with the existing restrictions [25].

Its mathematical representation is as follows;

$$Min\ Z = \sum_{i=1}^{t} (d_i^+ + d_i^-) \quad (1)$$

$$\sum_{j=1}^{n} w_{ij} x_j - d_i^+ + d_i^- = k_i \quad (2)$$

$$d_i^+ * d_i^- = 0 \quad (3)$$

$$x_j, d_i^+, d_i^- \geq 0 \qquad i = 1 \ldots t \quad j = 1 \ldots n \tag{4}$$

Variables;
$x_j = j$. decision variable
w_{ij}=i. your target j. decision variable weight coefficient
$k_i = i$. the desired value for the target
$d_i^+ = i$. positive bias variable of the target
$d_i^- = i$. negative bias variable of the target.

In the mathematical model above, (1) represents the objective function of the model and (2) represents the closed format of the constraints of the model. (3) indicates that when one of the positive and negative deviations takes value, the other will be zero, while (4) indicates that all variables must be greater than zero.

In goal programming, first of all, the decision maker should determine the goals and write these goals together with their weights and deviations as restrictions. One of the deviations must be zero so that the deviation variables in the restrictions do not take negative values and do not take values both above and below the target. This is possible by setting the product of the deviations to zero. Then, the deviations in the targets are minimized by writing the deviations into the objective function according to their order of importance or weight [26].

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

3. CASE STUDY

In the endocrinology, eye diseases, internal medicine clinic and ear-nose-throat clinic located in Ankara City Hospital General Hospital (MH-1) block, which is the application area of this study, problems are experienced because permanent nurses are not assigned to shifts equally and fairly. With this study, it is aimed to create a monthly work schedule for November 2020 by ensuring that a total of 50 nurses in 4 clinics are assigned to shifts as equally and fairly as possible. While creating the table, the monthly working hours specified in the law, the working rules of the hospital, Covid-19 measures, the demands and special situations of the nurses were taken into account. Since hospitals are institutions that provide continuous service, they work with a shift system. The hospital where the study was conducted works in a shift system and has three shifts: daytime (08.00-16.00), night (16.00-08.00), full-time (08.00-08.00).

While conducting this study, firstly, the problem of not equal and fair assignment of nurses to shifts was determined by interviewing the head nurse of Ankara City Hospital General Hospital (MH-1) block. During problem determination, data such as the number of nurses required for the study, shift hours, hospital rules were collected. Afterwards, a mathematical model was established and the solution was made and the results were evaluated. The application steps followed in the study are given in Figure 1.

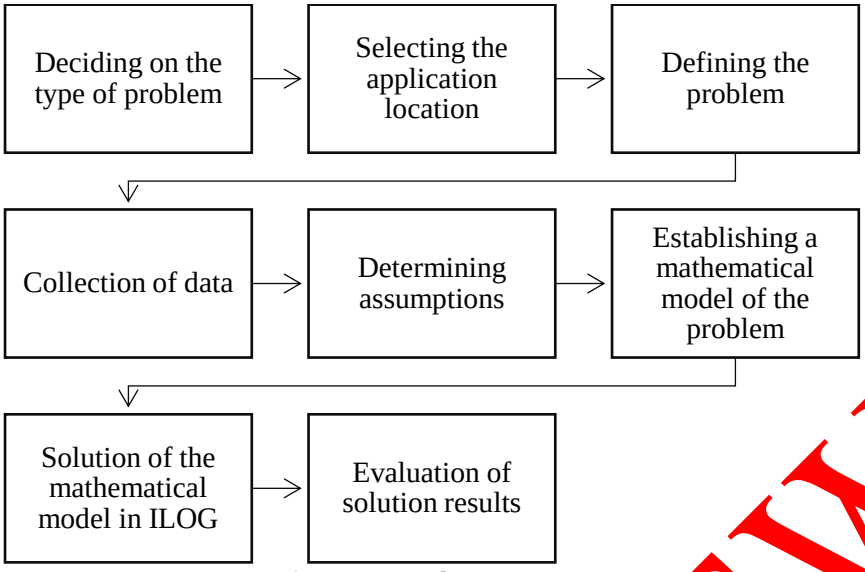

Figure 1. *Application steps*

Of the 50 nurses in this study, 8 are the responsible nurses of the clinics, 5 are pregnant nurses and the remaining 37 are normal nurses. Unlike normal nurses, responsible nurses and pregnant nurses, they can work in every clinic. All nurses are required to be assigned to shifts, not exceeding the monthly working hours specified in the law. In addition, the total number of shifts per month and the number of full-time shifts of normal nurses should be as equal as possible. In addition, the internal medicine clinic in the hospital has been transformed into a "Covid-19 Clinic", but the working structures and leave status of the nurses are the same for this clinic. In order to do this, a goal programming model has been developed.

Working rules taken into account while making this application;

*For responsible nurses and regular nurses, a maximum of 160 hours of work per month specified in the laws must be completed.

*Responsible nurses can only work day and night shifts in their own clinics.

*Normal nurses can work in all 4 clinics.

*The required number of nurses determined for each shift should be provided every day.

*Each nurse should be assigned to only one of the assigned shifts per day.

*The nurse working the night shift should not be assigned to the day, night and full-time shifts the next day.

*A nurse working a full-time shift must be on leave for 48 hours after the day she works.

*Responsible nurses can only work day and night shifts in their own clinics.

*Pregnant nurses should be assigned to only day shifts for a total of 12 shifts per month.

*During the Covid-19 global epidemic, the internal medicine clinic was used as the “Covid-19 Clinic”.

*Pregnant nurses can only be assigned to the day shift in the endocrinology clinic, eye diseases clinic and ear-nose-throat clinic.

*Pregnant nurses who are in the high risk group for the transmission of the virus and nurses over fifty (numbers 36 and 43) should not be assigned to the Covid-19 Clinic.

*Nurses with young children (number 12, 25 and 40) should not be assigned to full-time shifts.

*Normal nurses can keep a minimum of 3 and a maximum of 4 night shifts per month.

*Normal nurses work 12 shifts in total, 2 of which are full-time shifts per month.

*Nurses' one hour lunch break is included in the working hours.

*The numbers corresponding to the nurses in charge of the clinics, normal nurses and pregnant nurses in the mathematical model are given in Table 1.

Table 1. *Nurses and Numbers*

Nurses	**Numbers**	**Nurses**	**Numbers**
Endocrinology Clinic Responsible Nurses	1,2	Ear-Nose-Throat Clinic Responsible Nurses	7,8
Eye Diseases Clinic Responsible Nurses	3,4	Normal Nurses	9,10,11,…,45
Covid-19 Clinic Responsible Nurses	5,6	Pregnant Nurses	46,47,48,49,50

Parameters:

n = Number of working nurses $n=50$

m = Number of days $m=30$

s = Number of shifts $s=3$

t = Number of clinics $t=4$

Indices:

i = Nurse index $i=1,\ldots,n$

j = day index $j=1,\ldots,m$

k = shift index $k=1,\ldots,s$

l = clinical index $l=1,\ldots,t$

"1" for day shift, "2" for night shift and "3" for full day shift in shift index; "1" corresponds to endocrinology clinic, "2" to Covid-19 clinic, "3" to eye diseases clinic and "4" to ear-nose-throat clinic in the clinical index.

Deviation Variables:

$d1_i^+$ = i. the amount of positive deviation of the nurse from the 1st target ($i=1,2,\ldots,45$)

$d1_i^-$ = i. the amount of negative deviation of the nurse from the 1st target ($i=1,2,\ldots,45$)

$d2_i^+$ = i. the amount of positive deviation of the nurse from the 2nd target ($i=9,10,\ldots,45$)

$d2_i^-$ = i. the amount of negative deviation of the nurse from the 2nd target ($i=9,10,\ldots,45$)

$d3_i^+$ = i. the amount of positive deviation of the nurse from the 3rd target ($i=9,10,\ldots,45$)

$d3_i^-$ = i. the amount of negative deviation of the nurse from the 3rd target ($i=9,10,\ldots,45$)

Decision Variables:

$$x_{ijkl} = \begin{cases} 1, if\ nurse\ i\ is\ assigned\ to\ shift\ k, on\ j\ day, in\ l\ clinic, \\ 0, otherwise \end{cases}$$

$i=1,2\ldots,n,\ j=1,2,\ldots,m,\ k=1,2,\ldots,s,\ l=1,2,\ldots,t.$

$$h_{ijl} = \begin{cases} 1, if\ nurse\ off\ day\ on\ j\ day, in\ l\ clinic \\ 0, otherwise \end{cases}$$

$i=1,2\ldots,n,\ j=1,2,\ldots,m,\ l=1,2,\ldots,t.$

Restrictions:

Restriction 1: Each nurse should be assigned to only one of the designated shifts per day

$$\sum_{k=1}^{3}\sum_{l=1}^{4} x_{ijkl} \leq 1, \qquad i = 1,2,..,n, \qquad j = 1,2,\dots,m. \tag{5}$$

Restriction 2: The number of nurses assigned for each shift per day should not be less than the specified number

$$\sum_{i=1}^{50} x_{ij1l} \geq 13, \qquad j = 1,2,\dots,m, \qquad l = 1,2,..,s, \tag{6}$$

$$\sum_{i=1}^{50} x_{ij2l} \geq 7, \qquad j = 1,2,\dots,m, \qquad l = 1,2,..,s, \tag{7}$$

$$\sum_{i=1}^{50} x_{ij3l} \geq 5, \qquad j = 1,2,\dots,m, \qquad l = 1,2,..,s. \tag{8}$$

Restriction 3: Responsible nurses should not be assigned to full-time shifts

$$x_{ij3l} = 0, \;\; i = 1,2,\dots,8, \;\; j = 1,2,\dots,m, \;\; l = 1,2,..,s. \tag{9}$$

Restriction 4: The responsible nurses of each clinic should only be assigned to their own clinic

$$x_{1jkl} = 0, \;\; j = 1,2,\dots,m, \qquad k = 1,2, \qquad l = 2,3,4, \tag{10}$$

$$x_{2jkl} = 0, \;\; j = 1,2,\dots,m, \qquad k = 1,2, \qquad l = 2,3,4, \tag{11}$$

$$x_{3jkl} = 0, \;\; j = 1,2,\dots,m, \qquad k = 1,2, \qquad l = 1,3,4, \tag{12}$$

$$x_{4jkl} = 0, \;\; j = 1,2,\dots,m, \qquad k = 1,2, \qquad l = 1,3,4, \tag{13}$$

$$x_{5jkl} = 0, \;\; j = 1,2,\dots,m, \qquad k = 1,2, \qquad l = 1,2,4, \tag{14}$$

$$x_{6jkl} = 0, \;\; j = 1,2,\dots,m, \qquad k = 1,2, \qquad l = 1,2,4, \tag{15}$$

$$x_{7jkl} = 0, \;\; j = 1,2,\dots,m, \qquad k = 1,2, \qquad l = 1,2,3, \tag{16}$$

$$x_{8jkl} = 0, \;\; j = 1,2,\dots,m, \qquad k = 1,2, \qquad l = 1,2,3. \tag{17}$$

Restriction 5: Each nurse should not work more than 5 consecutive days

$$\sum_{i=1}^{4}(h_{ijl} + h_{i(j+1)l} + h_{i(j+2)l} + h_{i(j+3)l} + h_{i(j+4)l} + h_{i(j+5)l} \geq 1, \quad (18)$$
$i = 1,2,\dots,n, \qquad j = 1,2,\dots,m-5.$

Restriction 6: If any nurse is on a day off, ıt should not work that day

$$\sum_{k=1}^{3}\sum_{l=1}^{4} x_{ijkl} \leq \left(1 - h_{ij}\right), \;\; i = 1,2,..,n, \;\; j = 1,2,\dots,m. \quad (19)$$

Restriction 7: The nurse assigned to the night shift should not be assigned to the day, night and full day shifts the next day

$$\sum_{l=1}^{4}(x_{ij2l} + x_{i(j+1)1l} + x_{i(j+1)2l} + x_{i(j+1)3l}) \leq 1, \quad (20)$$
$i = 1,2,..,n, \;\; j = 1,2,\dots,m-1.$

Restriction 8: The nurse assigned to a full-time shift must be on leave for 48 hours

$$\sum_{l=1}^{4}(x_{ij3l} + x_{i(j+1)1l} + x_{i(j+1)2l} + x_{i(j+1)3l} + x_{i(j+2)1l} + x_{i(j+2)2l} + x_{i(j+2)3l}) \leq 1, \quad (21)$$
$i = 1,2,..,n, \;\; j = 1,2,\dots,m-1.$

Restriction 9: The maximum number of night shifts required by normal nurses per month should be met

$$\sum_{j=1}^{30}\sum_{l=1}^{4} x_{ij2l} \leq 4, \qquad i = 9,10,\dots,45. \quad (22)$$

Restriction 10: The minimum number of night shifts required by normal nurses per month should be met

$$\sum_{j=1}^{30}\sum_{l=1}^{4} x_{ij2l} \geq 3, \qquad i = 9,10,\dots,45. \quad (23)$$

Restriction 11: Pregnant nurses; should be assigned only to the day shift in the endocrinology clinic, eye diseases clinic and ear-nose-throat clinic

$$\sum_{j=1}^{30}\sum_{k=2}^{3} x_{ijk2} = 0, \qquad i = 46,47,\dots,50. \quad (24)$$

Restriction 12: The maximum number of shifts that pregnant nurses will work per month should be met

$$\sum_{j=1}^{30}\sum_{l=1}^{4} x_{ij1l} = 12, \qquad i = 46,47,\dots,50. \quad (25)$$

Restriction 13: Nurses 12, 25 and 40 should not be assigned to full-time shifts in any clinic because they have small children

$$x_{12j3l} = 0, \quad j = 1,2,\dots,m, \qquad l = 1,2,3,4, \tag{26}$$
$$x_{25j3l} = 0, \quad j = 1,2,\dots,m, \qquad l = 1,2,3,4, \tag{27}$$
$$x_{40j3l} = 0, \quad j = 1,2,\dots,m, \qquad l = 1,2,3,4. \tag{28}$$

Restriction 14: Nurse 22 must be on annual leave between the 12th and 19th days

$$x_{22jkl} = 0, \quad j = 12,13,\dots 19, \quad k = 1,2,3, \quad l = 1,2,3,4. \tag{29}$$

Restriction 15: Nurses 36 and 43 should not be assigned to the Covid-19 clinic because they are older (over 50 years old)

$$x_{36jk2} = 0, \quad j = 1,2,\dots,m, \qquad k = 1,2,3, \tag{30}$$

$$x_{43jk2} = 0, \quad j = 1,2,\dots,m, \qquad k = 1,2,3. \tag{31}$$

Goals:

Goal 1: All nurses except pregnant nurses should work as much as possible for a maximum of 160 hours per month

$$\sum_{j=1}^{30}\sum_{l=1}^{4}(8x_{ij1l} + 16x_{ij2l} + 24x_{ij3l}) - d1_i^+ + d1_i^- = 160, \qquad i = 1,2,\dots,45. \tag{32}$$

Goal 2: The total number of shifts to which regular nurses are assigned in the monthly work schedule should be equal

$$\sum_{j=1}^{30}\sum_{l=1}^{4}(x_{ij1l} + x_{ij2l} + x_{ij3l}) - d2_i^+ + d2_i^- = 12, \qquad i = 1,2,\dots,45. \tag{33}$$

Goal 3: The appointment of regular nurses to full-time shifts in the monthly work schedule should be assigned as equally as possible

$$\sum_{j=1}^{30}\sum_{l=1}^{4} x_{ij3l} - d3_i^+ + d3_i^- = 2, \qquad i = 9,10,\dots 45. \tag{34}$$

Objective Function:

$$\min z = \sum_{i=1}^{45}(d1_i^+) + \sum_{i=9}^{45}((d2_i^+) + (d3_i^+)) \tag{35}$$

The model created for the problem was solved with the ILOG CPLEX 12.6.2.0 package program by entering the relevant data [27]. In the current situation, while the schedule was prepared manually by the nurse in charge and in long periods, the solution was realized in 7.33 seconds with the suggested goal programming model. According to the solution results obtained, the assignments of nurses to one month shifts are shown in Appendix. In Appendix-Table 3, "E" corresponds to endocrinology clinic, "Covid" to Covid-19 clinic, "G" to eye diseases clinic and "KBB" to ear-nose-throat clinic; “1” corresponds to day shift, “2” to night shift and “3” to full day shift.

4. RESULTS

Table 2. *Nurses' Montly Assigned Shift Numbers and Total Hours*

Nurse	Day	Night	Full	T. Shift	T.Hour	Nurse	Day	Night	Full	T.Shift	T. Hour
1	10	5	-	15	160	**26**	6	4	2	12	160
2	10	5	-	15	160	**27**	6	4	2	12	160
3	10	5	-	15	160	**28**	6	4	2	12	160
4	10	5	-	15	160	**29**	6	4	2	12	160
5	10	5	-	15	160	**30**	6	4	2	12	160
6	10	5	-	15	160	**31**	6	4	2	12	160
7	10	5	-	15	160	**32**	6	4	2	12	160
8	10	5	-	15	160	**33**	6	4	2	12	160
9	6	4	2	12	160	**34**	6	4	2	12	160
10	6	4	2	12	160	**35**	6	4	2	12	160
11	6	4	2	12	160	**36**	6	4	2	12	160
12	12	4	-	16	160	**37**	6	4	2	12	160
13	6	4	2	12	160	**38**	6	4	2	12	160
14	6	4	2	12	160	**39**	6	4	2	12	160
15	6	4	2	12	160	**40**	12	4	-	16	160
16	6	4	2	12	160	**41**	6	4	2	16	160
17	6	4	2	12	160	**42**	6	4	2	16	160
18	6	4	2	12	160	**43**	6	4	2	16	160
19	6	4	2	12	160	**44**	6	4	2	16	160
20	6	4	2	12	160	**45**	6	4	2	16	160
21	6	4	2	12	160	**46**	12	-	-	12	96
22	6	4	2	12	160	**47**	12	-	-	12	96
23	6	4	2	12	160	**48**	12	-	-	12	96
24	6	4	2	12	160	**49**	12	-	-	12	96
25	12	4	-	16	160	**50**	12	-	-	12	96

The number of nurses assigned to shifts on a monthly basis and their total working hours per month are shown in Table 2. Looking at the hours given in the table, the total monthly hours for all operators are distributed as equally and balanced as possible. As seen in this table, the deviation from the total hour target is 0. According to these results, Goal 1 has been achieved. Pregnant nurses were assigned to the 1st shift a total of 12 times per month. The objective function value of the model was found to be 18 with a solution time of 3.82 seconds. It can be seen that Goal 3 has been achieved as each nurse, except the responsible nurses and pregnant nurses, is assigned to the all-day shift twice a month.

Appendix -Table-3 gives a one-month work program created for a total of 50 nurses. While creating the program, the schedule was created taking into account the hospital rules, laws and Covid-19 precautions, and the restrictions specified in the mathematical model. It is observed that Restriction 1 is met by assigning each nurse to only 1 shift each day. Restriction 2 is met by ensuring that the number of nurses assigned each day is not less than the specified number. It is observed that the responsible nurses are assigned only to the 1st and 2nd shifts in their own clinics. Thus, Restriction 3 and Restriction 4 are satisfied. Restrictions 5 and 6 are met by ensuring that each nurse does not work for 5 consecutive days and is not assigned on the day she is on leave. Nurses assigned to the night shift are not assigned to day, night and full-time shifts

the next day, thus Restriction 7 is met. Nurses assigned to full-time shift are not assigned to day, night and full-time shifts for the next 2 days, thus Restriction 8 is met. Restriction 9 and Restriction 10 are met by assigning regular nurses to a maximum of 4 and at least 3 night shifts. Restriction 11 and Restriction 12 are met by assigning pregnant nurses to clinics 1, 3 and 4 only on day shifts. It is seen that nurses numbered 12,25 and 40 are not assigned to the full-time shift and nurses numbered 36,43 are not assigned to clinic number 2. Thus, Restriction 13 and Restriction 15 are satisfied. Since nurse number 22 is on annual leave between 12-19 days, Restriction 14 is met by not assigning a shift.

Thanks to this schedule, nurses' exposure to Covid-19 was kept to a minimum and a more suitable working environment was provided to protect their health. Taking into account the special conditions and wishes of the nurses, extra precautions were taken for nurses in the high-risk group in terms of transmission of the virus, and the mental and physical health of the nurses was protected. In addition, by turning only one clinic into a "Covid-19 Clinic", the virus was prevented from infecting patients in other clinics.

4. CONCLUSION AND DISCUSSIONS

The Covid-19 epidemic has affected the whole world, causing the death of millions of people, and the number of deaths is increasing day by day. This epidemic also caused the death of health personnel in hospitals where patients needed the most. Nurses constitute the most important part among health personnel in the fight against this epidemic. The mental and physical health of the nurses responsible for the care of the people treated in the hospital is the basis of their better service. However, the health of nurses is also in danger due to both long and tiring working hours and the Covid-19 outbreak. Hospitals are responsible for taking measures to protect nurses from these negativities.

In the hospital where this study was conducted, there were two shifts, 08.00-16.00 and 16.00-08.00, in the early days of the Covid-19 epidemic, and each nurse was working only in her own clinic. Due to the fact that the number of shifts was 2, the nurses were very tired and the shifts were combined due to the shortage of nurses in the clinics. Sometimes nurses could not even go home. This resulted in longer stays in the hospital and longer contact with the Covid-19 virus. In order to eliminate these problems, a 3-shift system was introduced as day (08.00-16.00), night (16.00-08.00), full-time (08.00-08.00), and now nurses other than the responsible nurses of the clinics are allowed to work in every clinic.

Endocrinology clinic, eye diseases clinic, internal medicine clinic and ear-nose-throat clinic located in Ankara City Hospital General Hospital (MH-1) block were chosen as the place of application. In the study, 50 nurses working in 4 clinics were assigned to shifts in a balanced and fair manner. A mathematical model has been established by taking into account the rules, laws and Covid-19 measures determined by the hospital, as well as the special situations and wishes of the nurses. Goal programming method was used to solve the problem. Assigning a total of 50 nurses to night, day and full-time shifts was done with the ILOG CPLEX Studio IDE program and the optimal solution was reached by finding the objective function value of 16. As a result of the study, the special situations and requests of the nurses were met, and a suitable working environment was provided for the nurses with a high risk of virus transmission. With this study, both the demands of the hospital were met and the productivity of the nurses increased and they worked in a more systematic way. It is also an important feature of this study that it is the first nurse scheduling study conducted according to the measures taken within the scope of Covid-19.

In future studies, different mathematical models can be obtained by evaluating different units of the hospital simultaneously or separately. In addition to nurses in the hospital, monthly or weekly shifts can be scheduled for other health personnel. Different methods such as integer programming and constraint programming can be used in scheduling nurses. For more nurses, more working days, more units and more shifts, heuristic algorithms can be used instead of mathematical models, and a new solution can be produced with special restricted goal programming, that takes into account the nurses' needs.

In addition, this study can be developed and carried out on disaster nursing for current disasters and emergencies. Hospitals are of great importance in natural events such as earthquakes, floods or human-made disasters. Hospitals provide psychological and social support as well as medical interventions to individuals affected by disasters. Nurses have very important roles and responsibilities in disaster

management. New solution results for disaster nursing can be obtained by adding new constraints to the mathematical model created in disasters and emergencies where hospitals are busy.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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APPENDIX

Table 3. *Montly Work Schedule of Nurses*

		Days																												
No	Clinic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	E	1			2		1		1		1		1		2		1		2		1		1		1		1		2		2
	Covid																														
	G																														
	KBB																														
2	E	2			1		1		2		1		1		1		1		1		2		2		1		1		1		2
	Covid																														
	G																														
	KBB																														
3	E																														
	Covid	1	2		1		1		1		1		1		1		2			2		2		1		1		1			2
	G																														
	KBB																														
4	E																														
	Covid	2		1			1		1		1		1		1		2		1		2		2		1		1		1		2
	G																														
	KBB																														
5	E																														
	Covid																														
	G	2		1		2		1		1		1		1		1		1		2		1		1		1		2		2	
	KBB																														
6	E																														
	Covid																														
	G	2		2	1		1		1		1		1		1		1		2		2		1		1		1			2
	KBB																														
7	E																														
	Covid																														
	G																														
	KBB	2		2	1		1		1		1		1		1		1		2		2		1		1		1			2
8	E																														
	Covid																														
	G																														
	KBB	1	2		1			1		1		2		1		1		1		2		2		1		1		1			2
9	E	2											1		2						1				1		3				
	Covid			3				1											2												
	G																1														
	KBB									2													1								
10	E												1											2		1					
	Covid		3																												

	G					1				1												2								
	KBB							2						1		1		2												3

Tablo 3. *Montly Work Schedule of Nurses (Continuation)*

		Days																												
No	Clinic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
11	E	3																					1								3
	Covid																		1							2					
	G							1							2		2				1										
	KBB					1					1		2																		
12	E	1	1				1		1		1		1		1		1														
	Covid				1																						1				
	G																		2				2		1				1		
	KBB																				2										2
13	E						2									3			2						1						
	Covid	2							1		1																				
	G													1																	
	KBB																				2		1				1				3
14	E						1																1		1						
	Covid										2		1														3				3
	G														2		2														
	KBB								1										1		2										
15	E						1		3			1				1						2				1			2		
	Covid																	2						1							
	G																														3
	KBB													1						2											
16	E									1					1																3
	Covid					1															3					1					
	G																2		2									2			
	KBB							1					1											2							
17	E					1		1		1				1						3					1		2				3
	Covid			2								2											1								
	G																														
	KBB																2														
18	E														1		1														
	Covid												1												3						
	G							1															1								
	KBB		3			1					2								2		2										2
19	E																														
	Covid												2		3										1						
	G					2		1			1							1		1			1				2				
	KBB	2																													3
20	E															2		2				1									
	Covid			3			2																				2			3	
	G								1															1							
	KBB										1			1						1											

Tablo 3. *Montly Work Schedule of Nurses (Continuation)*

		Days																												
No	Clinic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
21	E																		2												
	Covid					3			1		2														2						
	G																2						1							3
	KBB												1		1						1						1				
22	E					2							ANNUAL LEAVE															1		
	Covid	1	3																												
	G																													2
	KBB							1		2		3									1		2		1		1				
23	E						1				3					1		1												
	Covid	2												1						2										
	G																					2		2		1				
	KBB								1																				3	
24	E	3					2																							
	Covid												1						3					2			2			
	G								2						1															
	KBB										1						1					1				1				
25	E	1			1		1		1						1												2			
	Covid										1																			2
	G		2										1										1		1			1		
	KBB																1		1		2									
26	E																													3
	Covid											1		2		2														
	G		3					1												2										
	KBB					1												2				1		1		1				
27	E				2																								1	
	Covid					1		2		1		1										2			3						
	G														1															
	KBB																2		1											3
28	E	3							1						2									1						
	Covid						1				1		2																		
	G																1					2				1				
	KBB																		2											3
29	E										1		3									2					2			
	Covid				2											1														
	G						2		1									1							1				3		
	KBB																			1										
30	E													1				1					1							
	Covid			3			2									1														
	G								2											1										

	KBB									3															1			2		2

Tablo 3. *Montly Work Schedule of Nurses (Continuation)*

		Days																												
No	Clinic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
31	E					3							2							1											
	Covid														1																1
	G								1														2							
	KBB			2							2							1							1		3				
32	E																					2		2						
	Covid										1		1																		
	G					2												1								3			2		
	KBB		3					1							1					1											
33	E					2															1		2							2
	Covid															3			1						1						
	G							1				1		2																	
	KBB	3								1																					
34	E					2					1		1						1			2								3
	Covid																													
	G							3							1									1		2		2			
	KBB																1														
35	E											1												2			1				
	Covid		2							2				1			1		1			1									
	G					3																								3
	KBB																												2		
36	E						1															2					1				
	Covid																														
	G								2					2						1					1						2
	KBB		3								3					1		1													
37	E																							1							
	Covid								3			1		1															2		
	G																					2				1					
	KBB	1					1										3			2								2			
38	E										1												2							2
	Covid												1		1		3			1											
	G	2																									1				
	KBB			3				1																					2		
39	E					1																1									
	Covid										1				3			2								2					
	G												1							2				1				3			
	KBB							2																							1
40	E														1		1		1										2		
	Covid				2																		1		1		1				
	G						1		1				1																		2

	KBB	1	1							1										2										

Tablo 3. *Montly Work Schedule of Nurses (Continuation)*

		Days																												
No	Clinic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
41	E													2										1				3			3
	Covid											1										2									
	G							1									1														
	KBB		1			2				2									1												
42	E												1		1																
	Covid		3						1														2		2					2	
	G					3					1																1				
	KBB																		1		2										
43	E						1				1						2							2				1			
	Covid																														
	G				1				1					3												3					
	KBB																		1			2									2
44	E				2		1															2									
	Covid										2							1													
	G	3											1																		
	KBB								1						1					1				2		3					
45	E					1															1										
	Covid												1																		
	G							1							2								1				3				3
	KBB										2						2		1						2						
46	E				1							1			1											1					
	Covid																														
	G	1					1			1							1				1										
	KBB																		1				1					1			
47	E										1		1				1				1										
	Covid																														
	G					1									1				1				1				1			1	
	KBB								1																1						
48	E													1																	
	Covid																														
	G															1			1								1				
	KBB					1		1		1		1									1		1		1						1
49	E								1		1			1						1					1						
	Covid																														
	G				1											1		1				1					1			1	
	KBB						1																								
50	E											1		1												1		1			
	Covid																														
	G				1		1		1							1				1