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A decision support system for scheduling the shifts of physicians during COVID-19 pandemic

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ARTICLE INFO

Keywords:
Physician scheduling
COVID-19 pandemic
Decision support system
Mixed integer programming

ABSTRACT

The rapidly spreading COVID-19 pandemic has affected many people worldwide. Due to the high infectivity, countries make calls to stay at home or take measures such as lockdowns to ensure that people are least affected by the virus. Meanwhile, infected people are getting treatments: people who are slightly affected are quarantined at home, and those who are heavily affected are treated in hospitals. Hence there is an excessive increase in the hospital workload. This causes physical fatigue in healthcare professionals. Along with the increasing workload, the fear of being infected and infecting the environment causes psychological problems in healthcare professionals. It is important to protect healthcare professionals and provide them with suitable working conditions. For this reason, besides the provision of protective equipment such as gloves, overalls, mask, and glasses that are necessary for the protection of healthcare workers from the virus, healthcare services should also be planned very carefully. One of the critical issues is planning the shift schedules of the physicians. In this study, we handle the preparation of a physician shift schedule of a hospital in Turkey during the COVID-19 pandemic. The hospital has established three new COVID-19 related departments and the aim is to provide continuous service in the new departments while maintaining the workload in the existing departments. We propose a mixed integer programming (MIP) model to address the shift scheduling problem and transform it into a decision support system (DSS). The resulting schedules minimize the exposure of the physicians to the virus with a balanced workload while maintaining the healthcare service in all departments.

1. Introduction

World Health Organization (WHO) (WHO, 2010) defines pandemic to be the worldwide spread of a newly emerged epidemic. In history, many pandemics have threatened the world until today. Three important pandemics have been observed in the 20th century: Spanish influenza in 1918, Asian influenza in 1957, and Hong-Kong influenza in 1968 (Smith et al., 2009). As a result of these influenza pandemics affecting the masses, millions of people died (Kain and Fowler, 2019). Significant pandemics were observed in the 21st century as well (Bertolini et al., 2016). Many people in the world were affected by the SARS virus, which affected the world in 2003, and the swine flu that showed its effect in 2009. In this century, people from different communities can travel more and interact easily with each other as a result of the globalizing world. Hence infectious diseases can spread all over the world which increases the number of infected people very rapidly.

The COVID-19 virus appeared in Wuhan, China in late 2019, it spread all over the world in early 2020 and was declared as a pandemic by the WHO (Saglık Bakanlığı, 2020). After this date, the countries started to close their borders and tried to prevent the spread of the virus by declaring lockdowns. While some people who are slightly affected by the virus are quarantined at their home, some other people with severe conditions are either connected to the respirator or treated in intensive care units (ICU). As a result, the workload of hospitals (and hence healthcare professionals) has increased significantly. In other words, the physicians become one of the most affected groups from the COVID-19. Even if they use protective equipment such as protective gowns, masks, overalls, and glasses, they are affected both physically and psychologically by the virus with the fear of being affected and affecting their beloved ones. Therefore healthcare services should be planned very carefully to reduce the psychological burden on the healthcare professionals. Hence, the planning of shift schedules is more important than before. In Turkey, hospitals have been working in coordination with the Ministry of Health and the Scientific Committee in order to balance the density in the hospitals since March 10, 2020, when the first case was detected (Saglık Bakanlığı, 2020). In this study, we propose a

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https://doi.org/10.1016/j.cie.2020.106874

Available online 25 September 2020
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mathematical model, in particular a Mixed Integer Programming (MIP) model and develop a Decision Support System (DSS) to generate balanced shift schedules that provides minimal exposure to the virus for physicians.

The rest of the paper is organized as follows. Section 2 provides a literature review. In Section 3, we give the problem statement and propose our MIP model. Section 4 provides the details of the DSS and illustrates its implementation. We conclude in Section 5.

2. Literature review

This section is devoted to the review of the literature related to disaster/emergency management and physician scheduling problem (PSP). We first mention disaster management and planning and management of a pandemic. Then, we give PSP studies that are related to the fair schedules of physicians.

Natural disasters such as tsunamis, fire, earthquake and emergencies such as pandemics impact many people in general leaving people physically and mentally injured and even causing deaths. In order to overcome such disasters with minimal damage, precautions are taken through emergency plans. Miller et al. (2006) planned the recovery strategies that consist of four steps: mitigation, preparedness, response, and recovery. Then, they provided examples of the software which help management of the disaster and emergency situations. Such softwares provide a structure that helps thinking, highlight the emergency situations and questions, simplifying the complex situations. Sotoodeh and Kruchten (2008) considered disaster management as conceptual modeling. The authors stated that disaster management requires physical and social solidarity and hence many sectors should communicate with each other to work in a coordinated manner. Like Miller et al. (2006), Othman and Beydoun (2010) improved a model which is based on four phases: mitigation, preparedness, response, and recovery. They provided a DSS by using the language they developed. They provided unification, facilitation, and quick access to disaster management expertise by using this DSS and meta-model.

In emergencies such as natural disasters, it is important to understand the disaster and act in a way that can respond to it quickly in order to minimize damage. The aforementioned studies are the works carried out to act quickly and to provide emergency management. However, the pandemic has more difficulties when compared to natural disasters. In natural disasters, precautions to be taken in events such as tsunami, earthquakes, and fires are almost certain. A pandemic is the spread of a new disease worldwide, and the effect is greater since (i) most people are not immune to this virus (WHO, 2010), and (ii) the emergence pathway of pandemics is still unknown (Smith et al., 2009). Although the preparations to be made are more ambiguous in pandemics, studies can be carried out according to the results obtained from previous pandemics. Bertolini et al. (2016) emphasized ICUs in their study and mentioned that they support rapid diagnosis in emergency diseases. In other words, they stated that ICUs have an important role for public health. Kain and Fowler (2019) also conducted a study on intensive care preparation for the next pandemic. They created a five-step preparatory plan for the next pandemic: (i) surveillance of the new pandemics, (ii) a scalable system to respond to the surge, (iii) the production of the vaccines for the masses, (iv) integrated and coordinated communication and (v) harmonized proposals for faster initiation. Tseng and Yin (2008) provided information about the necessity and comprehensiveness of the crisis management systems. They made survey with the nurses which showed that nurses expect more support from their managers in crisis situations. Mirzaei, Eftekhari, reza Sadeghian, Kazemi, and Nadjarzadeh (2019) conducted a study to evaluate the knowledge of nurses about emergencies. In their study at a hospital in Yazd, they made a survey of nurses about accidents and diseases first. Then, they prepared a test for these nurses, who had undergone a one-day training, to observe effect of the education on emergency situations. Mirzaei et al. (2020) also made a survey with nurses. They applied a questionnaire to two group of nurses to test whether they were ready for natural disasters. After the survey, they provided training in which only theoretical knowledge was given to one group. They gave the other group training at the top of the tabletop with theoretical knowledge. Afterward, they re-made the exam with the same questions to both groups. The results revealed that besides the theoretical knowledge, the training given by tabletop was better. According to the result of aforementioned studies about pandemic preparations, the hospitals should be prepared for the emergency situation by having enough bed capacity at the hospital, especially in ICU, and giving proper education/information about the pandemic situations to the health personals. These pre-preparation can give the opportunity to saving more lives. In other words, these studies show the importance of being prepared for situations such as natural disasters and emergency situations and they emphasize the importance of responding to events as quickly as possible (Mishra et al., 2016).

Like the pre-preparation phase, the control of the process at the pandemic period has also great importance. Hospitals and healthcare workers play an important role in the pandemic. Physicians and nurses interact with infected people closely. In addition, even though COVID-19 has a lower mortality rate, its infectivity is more when it is compared the previous pandemics such as SARS and MERS (Lima et al., 2020). For this reason, hospital managers start to prepare their hospitals and get prepared to respond as quickly as possible by assigning new duties to the health workers. As a result of this, some new job descriptions are added to physicians’ responsibility. Thus, one of the most affected groups from the virus is healthcare workers. Therefore the healthcare workers need more protection with the work overload and high spread rate (Hick and Biddinger, 2020). Chang, Xu, Rebaza, Sharma, and Cruz (2020) analyzed protection of healthcare of health workers. They emphasized that it is important for healthcare workers to use protective equipment such as gloves, glasses, overalls, and mask to protect against this mucous-infected virus. The idea of being affected by the disease and transmitting the virus to the people mentally affect the physicians who already have an intense workload. Baneree (2020) indicated that the lack of the mental health affects the performance and health outcome of the medical staff. For this reason, they suggested that the psychiatrists have major impact of the supporting well-being of the health worker and their families and they provide some intervention areas for psychiatrists. Health workers need to be physically protected as well as the protection of mental health. Greenberg et al. (2020) proposed that properly preparing staff for the job reduces the risk of the mental health problems. Xiang and Al (2020) and Bearman and Al (2020) similar to Chang et al. (2020), Baneree (2020) and Greenberg et al. (2020), also suggested that the mental condition of healthcare professionals, and also the psychological condition of the patients/people should be managed. Dewey et al. (2020), on the other hand, handled the physical circumstances. They stated that rest-rooms should be arranged for health workers working with long shifts. Curkovic et al. (2020) also suggested that the shift schedules of the health workers should be rearranged. In their study, while the health workers working with infected patients were recommended working for 2-weeks and then to isolate themselves for 2 weeks, health workers who are interested in COVID-free patients can take a 48-hour rest after working one day.

In the PSP literature, we focus on the studies that address fair schedules or easy preparation of schedules via DSS. Güler, İdin, and Yilmaz Guler (2013) proposed a goal programming model to provide fair
schedule by satisfying the desires of physicians at the anesthesia and reanimation department. Fügener et al. (2015) constructed two different mathematical models to distribute equal shifts for each physician in a German hospital by maximizing labor regulations. First one, which is the duty-roster model, provides the determination of the assignment of the physicians to shifts, whereas, second model, the workstation-roster model, gives the assignment of the physicians to the workstations. Bowers et al. (2016), provided a novel approach for physicians shift schedule in the Neonatal-ICU at the University of Tennessee Medical Center in Knoxville. Their MIP model consists two steps: one of the step is the determination of the shifts, whereas, the other one is assigning physicians to these shifts. Gross (2018) constructed a quadratic mathematical model to prepare shift schedule for long-term time horizon by using indicator matrix which is used to define physician duties and then assigning equal shifts for physicians in a German University Hospital. The model was linearized to obtain a solution. Demci-Kurt et al. (2019) addressed PSP of Flagstaff Medical Center Hospitals to distribute equal workload. Gross et al. (2019) used mixed integer quadratic program with satisfaction matrix, which gives information of preference fulfillment of each physician. They used three different strategies for this matrix and obtained fair schedules for a German hospital. Camiat et al. (2019) proposed a MIP model which has two parts: (i) calculation of productivity of physicians, (ii) the assignment of physicians to allocate productivity with fairness. They used historical data to predict the demand and estimate the productivity of each physicians. Next, they reduced the difference between productivity and demand for each physician. Mansini and Zanotti (2019) proposed two different MIP models and they improved these models by using Adaptive Large Neighborhood Search algorithm. They minimized the total time spent by all physicians with their model. Schöenfelder and Pfefferlen (2018) proposed a mathematical model for the anesthesiology department of a hospital in Berlin. They used Microsoft (MS) Excel spreadsheet with a macro to construct a DSS for PSP. Smalley and Keskinocak (2016) gave two different integer programming models for creating feasible assignment of interns in the long time horizon and created night and weekend call shifts. By using these models and macros of MS Excel, they created a DSS to provide continuity of healthcare and to prevent the attrition of the interns.

The aforementioned PSP studies address creating fair schedules for physicians during COVID-free periods. Moreover, only two studies, Schöenfelder and Pfefferlen (2018) and Smalley and Keskinocak (2016), provided easy preparation of shift schedules by creating DSS in addition to fair schedules. However, to the best of our knowledge, this is one of the earliest studies addressing the scheduling problem of healthcare workers (in particular physicians) in a pandemic. The problem is different from classical PSP in the sense that physicians with different professions has to work together in shifts of newly established COVID-19 departments. We propose a MIP model that addresses this problem and create a balanced workload among the healthcare workers. The MIP model is transformed into a DSS which is flexible and can be used by any hospital with slight modifications during the pandemic.

3. Problem definition and mathematical model

In this section, we give first the problem definition and then we give the mathematical model for this problem.

3.1. Problem definition

We study the PSP of a hospital in Turkey which is the largest hospital of the city providing health care to regular patients and to people who are affected by the Coronavirus. There are 14 regular departments that are actively working in the hospital such as internal medicine, urology, cardiology, brain surgery, etc. These departments continue their daily routine operations in the pandemic period, hence physicians work in the shifts of these departments which we called as the regular shifts. In order to cope with the pandemic, the management has established three new departments to serve those who are infected by Coronavirus (i.e., COVID-19 Departments): COVID-Service, COVID-ICU, and COVID-Emergency. COVID-Emergency welcomes the patient and directs those patients who are severe (needing intubation, for example) to COVID-ICU and those who are mild to COVID-Service. The COVID-19 departments are staffed with the current physicians. Therefore in addition to their own workload in their departments, the physicians have to work in the shifts of COVID-19 departments, i.e., COVID-19 shifts, which increased their workload significantly.

Following rules should be met for a legitimate working schedule:

- COVID-ICU has two shifts: (i) day shift and (ii) night shift. The day shift starts at 08:00 and ends at 20:00. The night shift, on the other hand, starts at 20:00 and lasts until the next day morning at 08:00. There must be three physicians in each shift.
- COVID-Service has also a day (08:00-20:00) and a night (20:00-08:00) shift that lasts twelve hours each. There should be three physicians.
- COVID-19 is a new type of disease and the patients can come up with different complications. Therefore the hospital management decided that it’s better to allocate physicians from different professions at each COVID-ICU and COVID-Service shifts.
- COVID-Emergency has three shifts of eight hours. The first shift starts at 08:00 and lasts until 16:00. The second shift begins at 16:00 and ends at 24:00. The last shift is between 24:00 and the next day at 08:00. For each shift, one physician must be assigned to the shift.
- The hospital is not a pandemic hospital in the sense that the other departments, although the rate is low, still provide health care service. Therefore, the physicians work in shifts of their own regular shifts in addition to the COVID-19 shifts. Every department has its own 24-hour regular shift. The number of needed physicians for each regular shift depends on the number of physicians in the department.
- Some physicians are not eligible for particular shifts of COVID-19 departments. For example a neurosurgeon or a general surgeon can work in COVID-ICU but an urologist cannot.
- One of the key issue for being affected is the amount of exposure to the virus. Therefore exposure of physicians to the corona virus should be minimized as much as possible. In order to achieve this, the shifts should be distributed to physicians evenly. This is also important for keeping the morale of the physicians high since they are very sensitive about number of shifts due to the risk of being infected and then infecting others. Distributing shifts evenly can be achieved in two steps. First, physicians in the same department should have similar COVID-19 shifts. For example the physicians in urology should have similar (preferably same) number of shifts in COVID-Service. In the second level, number of COVID-19 shifts of physicians from different departments should not vary too much. For example number of COVID-ICU shifts for general surgery and internal medicine must be close (preferably equal) to each other. We will elaborate on this further in the mathematical model and the implementation phase.
- There should be one off-day between the shifts. A physician does not work in an off-day. Furthermore, there can be two off-days between consecutive two shifts, if possible.
The total number of physicians in the departments and distribution of regular shifts and COVID-19 shifts is given in Table 1. The first column (department) gives active departments in the hospital. The second column (number of physicians) shows the available number of physicians at the regular departments. The third column shows the number of physicians needed at the regular shifts. The last three columns show whether the departments are eligible to work respectively in COVID-ICU, COVID-Service, and COVID-Emergency departments or not. For example, internal medicine physicians can work in COVID-ICU but cannot work in COVID-Service or COVID-Emergency. The last department (Pool) in the table is a mixed category of departments like hematology, physical therapy, pediatrics, etc. There are few number of physicians in the departments of pool group and it is decided to merge these departments in a single group to enhance the scheduling process during the pandemic. Although the departments in the pool do not have a regular shift, the hospital management decided to employ them in the shift of chest diseases department which is one of the largest units in the hospital. Therefore the regular shift of a physician in the pool work in the chest diseases department as a regular shift.

In the next section we give the details of the MIP model that addresses the problem defined above.

Table 2

| Department | Num. of Physicians | Regular Shifts | COVID-ICU | COVID-Service | COVID-Emergency |
|------------|--------------------|----------------|-----------|---------------|----------------|
| Orthopedics | 7                  | 1              | 0         | 1             | 1              |
| Traumatology|                    |                |           |               |                |
| Urology    | 4                  | 1              | 0         | 1             | 1              |
| Eye Center | 7                  | 1              | 0         | 1             | 1              |
| Ear, Nose and Throat Disorders | 5 | 1 | 0 | 1 | 1 |

The sets and parameters.

Set | Definition
--- | ---
і | Index and set of physicians
І | Index and set of days
d/D | Index and set of departments
s/S(d) | Index and set of shift type for each department d
I \_r | Set of physicians working in regular department r
I \_c | Set of physicians eligible to work at COVID-19 department c
N \_d | Required number of physicians at department d
D \_r | Regular departments (such as orthopedics, internal medicine, etc.) in the hospital
D \_c | COVID-19 departments (COVID-ICU, COVID-Service, COVID-Emergency) in the hospital
ML \_d | The limit between the minimum and the maximum number of shifts of physician in regular department r in a month in department d
ML \_d | The limit between the minimum and the maximum number of shifts of physician in COVID-19 department r in a month in department d
k \_d | Penalty value for the deviation variable U \_d

Table 3

The variables.

Variable | Definition
--- | ---
X \_іd | 1 if physician i is working on shift s on day t at department d
MD \_іd | Minimum number of shifts performed by a physician of regular department r at department d in a month
MD \_іd | Maximum number of shifts performed by a physician of regular department r at department d in a month
ML \_d | Minimum number of shifts performed by a physician at department d in a month
ML \_d | Maximum number of shifts performed by a physician at department d in a month
U \_d | Deviation variable that allows rest for two consecutive days for physician i, day t

\[ \sum_{i \in I, d \in D} X_{іd} \leq 1 \quad t \in T, \ c \in D, \ s \in S(d), \ r \in D_k \] (4)

\[ \sum_{d \in D} \sum_{s \in S(d)} (X_{іd} + X_{і+1}d) \leq 1 \quad i \in I, \ t \in T, \ t + 1 \in T \] (5)

\[ \sum_{d \in D} \sum_{s \in S(d)} (X_{іd} + X_{і+1}d + X_{і+2}d) \leq 1 + U \_d \quad i \in I, \ t \in T, \ t + 1 \in T, \ t + 2 \in T \] (6)

\[ MD_{іd}^{max} - MD_{іd}^{min} \leq MDL_{іd} \quad r \in D_k, \ i \in I, \ d \in D \] (7)

\[ \sum_{i \in I, d \in D} X_{іd} \leq MD_{іd}^{max} \quad r \in D_k, \ i \in I, \ d \in D \] (8)

\[ ML_{іd}^{min} \leq \sum_{i \in I, d \in D} X_{іd} \quad d \in D_c, \ i \in I \_d \] (10)

\[ \sum_{i \in I, d \in D} X_{іd} \leq ML_{іd}^{max} \quad d \in D_c, \ i \in I \_d \] (11)

\[ ML_{іd}^{max} - ML_{іd}^{min} \leq MLL_{іd} \quad d \in D_c \] (12)
Table 4
Number of shifts for physicians.

| No | Physicians | Total Shift | C-ICU | C-E | C-S | R | No | Physicians | Total Shift | C-ICU | C-E | C-S | R | No | Physicians | Total Shift | C-ICU | C-E | C-S | R |
|----|-------------|-------------|-------|-----|-----|---|----|-------------|-------------|-------|-----|-----|---|----|-------------|-------------|-------|-----|-----|---|
| 1  | ORT. Dr.1   | 10          | 0     | 2   | 4   | 4 | 29 | R. Dr.1     | 11          | 0     | 2   | 4   | 5 | 57 | IM. Dr.6    | 14          | 6     | 0   | 0   | 8 |
| 2  | ORT. Dr.2   | 10          | 0     | 2   | 4   | 4 | 30 | R. Dr.2     | 12          | 0     | 2   | 4   | 6 | 58 | IM. Dr.7    | 15          | 6     | 0   | 0   | 9 |
| 3  | ORT. Dr.3   | 10          | 0     | 2   | 4   | 4 | 31 | R. Dr.3     | 11          | 0     | 2   | 4   | 5 | 59 | CD. Dr.1    | 12          | 0     | 2   | 3   | 7 |
| 4  | ORT. Dr.4   | 11          | 0     | 2   | 4   | 5 | 32 | R. Dr.4     | 11          | 0     | 2   | 4   | 5 | 60 | CD. Dr.2    | 13          | 0     | 2   | 3   | 8 |
| 5  | ORT. Dr.5   | 10          | 0     | 2   | 4   | 4 | 33 | R. Dr.5     | 11          | 0     | 2   | 4   | 5 | 61 | CD. Dr.3    | 12          | 0     | 1   | 3   | 8 |
| 6  | ORT. Dr.6   | 11          | 0     | 2   | 4   | 5 | 34 | R. Dr.6     | 10          | 0     | 2   | 3   | 5 | 62 | CD. Dr.4    | 12          | 0     | 1   | 3   | 8 |
| 7  | ORT. Dr.7   | 11          | 0     | 2   | 4   | 5 | 35 | Psy. Dr.1   | 11          | 0     | 2   | 4   | 5 | 63 | N. Dr.1     | 13          | 6     | 0   | 0   | 7 |
| 8  | URO. Dr.1   | 12          | 0     | 1   | 3   | 8 | 36 | Psy. Dr.2   | 11          | 0     | 1   | 4   | 6 | 64 | N. Dr.2     | 14          | 6     | 0   | 0   | 8 |
| 9  | URO. Dr.2   | 11          | 0     | 1   | 3   | 7 | 37 | Psy. Dr.3   | 11          | 0     | 2   | 4   | 5 | 65 | N. Dr.3     | 14          | 6     | 0   | 0   | 8 |
| 10 | URO. Dr.3   | 12          | 0     | 1   | 3   | 8 | 38 | Psy. Dr.4   | 11          | 0     | 2   | 4   | 5 | 66 | N. Dr.4     | 14          | 6     | 0   | 0   | 8 |
| 11 | URO. Dr.4   | 12          | 0     | 1   | 3   | 8 | 39 | Psy. Dr.5   | 11          | 0     | 2   | 4   | 5 | 67 | BS. Dr.1    | 14          | 6     | 0   | 0   | 8 |
| 12 | EC. Dr.1    | 11          | 0     | 2   | 4   | 5 | 40 | Psy. Dr.6   | 11          | 0     | 2   | 4   | 5 | 68 | BS. Dr.2    | 13          | 6     | 0   | 0   | 7 |
| 13 | EC. Dr.2    | 11          | 0     | 2   | 4   | 5 | 41 | Pool Dr.1   | 8           | 0     | 2   | 4   | 2 | 69 | BS. Dr.3    | 14          | 6     | 0   | 0   | 8 |
| 14 | EC. Dr.3    | 10          | 0     | 2   | 4   | 4 | 42 | Pool Dr.2   | 9           | 0     | 2   | 4   | 3 | 70 | BS. Dr.4    | 14          | 6     | 0   | 0   | 8 |
| 15 | EC. Dr.4    | 10          | 0     | 2   | 4   | 4 | 43 | Pool Dr.3   | 9           | 0     | 2   | 4   | 3 | 71 | CVS. Dr.1   | 14          | 6     | 0   | 0   | 8 |
| 16 | EC. Dr.5    | 10          | 0     | 2   | 4   | 4 | 44 | Pool Dr.4   | 9           | 0     | 2   | 4   | 3 | 72 | CVS. Dr.2   | 13          | 6     | 0   | 0   | 7 |
| 17 | EC. Dr.6    | 10          | 0     | 2   | 4   | 4 | 45 | Pool Dr.5   | 9           | 0     | 2   | 4   | 3 | 73 | CVS. Dr.3   | 14          | 6     | 0   | 0   | 8 |
| 18 | EC. Dr.7    | 11          | 0     | 2   | 4   | 5 | 46 | Pool Dr.6   | 9           | 0     | 2   | 4   | 3 | 74 | CVS. Dr.4   | 14          | 6     | 0   | 0   | 8 |
| 19 | ENT Dr.1    | 11          | 0     | 2   | 3   | 6 | 47 | Pool Dr.7   | 9           | 0     | 2   | 4   | 3 | 75 | C. Dr.1     | 15          | 6     | 0   | 0   | 9 |
| 20 | ENT Dr.2    | 12          | 0     | 2   | 3   | 7 | 48 | Pool Dr.8   | 8           | 0     | 2   | 4   | 2 | 76 | C. Dr.2     | 15          | 6     | 0   | 0   | 9 |
| 21 | ENT Dr.3    | 11          | 0     | 2   | 3   | 6 | 49 | Pool Dr.9   | 9           | 0     | 2   | 4   | 3 | 77 | C. Dr.3     | 15          | 6     | 0   | 0   | 9 |
| 22 | ENT Dr.4    | 11          | 0     | 2   | 3   | 6 | 50 | Pool Dr.10  | 9           | 0     | 2   | 4   | 3 | 78 | C. Dr.4     | 14          | 6     | 0   | 0   | 8 |
| 23 | ENT Dr.5    | 11          | 0     | 2   | 3   | 6 | 51 | Pool Dr.11  | 9           | 0     | 2   | 4   | 3 | 79 | C. Dr.5     | 15          | 6     | 0   | 0   | 9 |
| 24 | GS. Dr.1    | 12          | 0     | 0   | 0   | 6 | 52 | IM. Dr.1    | 15          | 6     | 0   | 0   | 9 | 80 | C. Dr.6     | 15          | 6     | 0   | 0   | 9 |
| 25 | GS. Dr.2    | 12          | 0     | 0   | 0   | 6 | 53 | IM. Dr.2    | 15          | 6     | 0   | 0   | 9 | 81 | C. Dr.7     | 15          | 6     | 0   | 0   | 9 |
| 26 | GS. Dr.3    | 12          | 0     | 0   | 0   | 6 | 54 | IM. Dr.3    | 15          | 6     | 0   | 0   | 9 | 82 | CVS. Dr.1   | 14          | 6     | 0   | 0   | 8 |
| 27 | GS. Dr.4    | 12          | 0     | 0   | 0   | 6 | 55 | IM. Dr.4    | 15          | 6     | 0   | 0   | 9 | 83 | CVS. Dr.2   | 13          | 6     | 0   | 0   | 7 |
| 28 | GS. Dr.5    | 13          | 0     | 0   | 0   | 7 | 56 | IM. Dr.5    | 15          | 6     | 0   | 0   | 9 | 84 | CVS. Dr.3   | 14          | 6     | 0   | 0   | 8 |

Note: R: Regular Shifts, Departments: C-ICU: COVID-ICU, CS: COVID-Service, C-E: COVID-Emergency, ORT: Orthopedics, URO: Urology, EC: Eye Center, ENT: Ear, Nose and Throat Disorders, GS: General Surgery, R: Radiology, Psy: Psychiatry, IM: Internal Medicine, CD: Chest Diseases, N: Neurology, BS: Brain Surgery, CVS: Cardiovascular Surgery, C: Cardiology.
\[
\begin{align*}
X_{idt} &\in \{0, 1\} \quad i \in I, \ t \in T, \ d \in D, \ s \in S(d) \\
U_{it} &\in (0, 1) \quad i \in I, \ t \in T \\
ML_d^{\text{min}}, ML_d^{\text{max}}, MD_r^{\text{min}}, MD_r^{\text{max}} &\geq 0 \quad d \in D, \ r \in D_R, s \in S(d), \ r \in D_R, s \in S(d)
\end{align*}
\]

(13)

Constraint (2) states that a physician can have at most one shift in a day. Constraint (3) ensures that sufficient number of physicians are assigned for each shift in a department. This constraint also prohibits assigning non-eligible physicians to departments. A critical issue for COVID-19 departments is to allocate physicians with different professions for the COVID-19 shifts. For example, in the COVID-ICU shift, three physicians can be from neurology, brain surgery, and cardiovascular surgery, but there cannot be two physicians from cardiovascular surgery. Constraint (4) ensures that physicians involved in a COVID-19 shift are from different departments. Constraint (5) ensures that each physician has one off-day between consecutive shifts. Constraint (6) provides two off-days between consecutive shifts, if possible. It’s a soft constraint in the sense that the system does not set two off-days between consecutive shifts if it is not possible. The deviation in this constraint is minimized in the objective function. Constraints (7)-(9) ensure that physicians working in the same department have (i) equal regular shifts in their own department and (ii) equal COVID-19 shifts in each COVID-19 department. In order to illustrate this, consider radiologists for example. They are eligible to work in COVID-Service and COVID-Emergency. The constraint set in (7)-(9) ensures that radiologists have (i) similar (preferably the same) amount of shifts in radiology department, (ii) similar (preferably the same) amount of shifts in COVID-Service, (iii) similar (preferably the same) amount of shifts in COVID-Emergency. In particular, constraints (7) and (8) show the minimum and maximum total number of shifts in department \( d \) assigned to a physician from a regular department \( r \). Constraint (9) ensures that the difference between the maximum and the minimum number of these shifts are limited. Constraints (10)-(12) state that the total number of shifts assigned to any physician \( i \) in a COVID-19 department \( d \) should be the similar (preferable the same). In order to illustrate, consider the following example about radiologists and psychiatrists. Both group of specialists are eligible to work in COVID-Service and COVID-Emergency. These constraints state that a radiologist and a psychiatrist should have (i) similar (preferably the same) amount of shifts in COVID-Service and (ii) similar (preferably the same) amount of shifts in COVID-Emergency. In another words, the equality of COVID-19 shifts should not depend on the department of a physician. Constraint (10) and (11) respectively show the minimum and maximum number of COVID-19 shifts in COVID-19 Department \( d \) performed by physician \( i \). Constraint (12) ensures that the difference between the maximum and the minimum number of these shifts are limited. Note that these two sets of constraints, i.e., Constraints (7)-(9) and constraints (10)-(12) are not substitutes of each other. For example, a decision maker can set the difference for COVID-ICU in constraint (12) to one, so that COVID-ICU shifts of all of the physicians will differ by one at most. The same decision maker can set

| Shifts according to the COVID-19 departments | Average number |
|---------------------------------------------|----------------|
| Shifts per physician at COVID-ICU           | 6              |
| Shifts per physician at COVID-Service       | 3.72           |
| Shifts per physician at COVID-Emergency     | 1.86           |

| Shifts according to the regular departments. | Average number |
|---------------------------------------------|----------------|
| Orthopedics and Traumatology                | 10             |
| Urology                                     | 12.25          |
| Eye Center                                  | 10.15          |
| Ear, Nose and Throat Disorders              | 12             |
| General Surgery                             | 12.2           |
| Radiology                                   | 11             |
| Psychiatry                                  | 11             |
| Internal Medicine                           | 14.86          |
| Chest Diseases                              | 13             |
| Neurology                                   | 13.75          |
| Brain Surgery                               | 13.75          |
| Cardiovascular Surgery                      | 13.75          |
| Cardiology                                  | 14.86          |
| Pool                                        | 8.45           |

Table 5
The average number of shifts of departments.
difference for COVID-ICU for general surgery to zero in constraint (9) so that all of the general surgeons have equal COVID-ICU shifts. The non-negativity constraints are given in (13).

The objective is to minimize the deviation variable. This is intuitive since this is an emergency situation and the aim is to prepare feasible schedules rather than addressing personal preferences like asking for off days for birthdays or watching football or NBA matches. The penalty values, $k_r$, in the objective function in Eq. (1) is simply 1 in the current version of the model however we keep it as it is to enable a user to define different weights for different departments, physicians or days.

4. Implementation

In this part of the study, we give preparation and implementation of the DSS to generate shift schedules at COVID-19 pandemic period for the 81 physicians of the hospital. We created the DSS by using MS Excel spreadsheet and its add-in Solver Studio (Solver Studio, 2016). We coded the MIP model using Python and used Gurobi to solve the model. The MIP model is the core of the DSS and to prepare this DSS, we defined input and output fields both of which were written into MS Excel spreadsheets. Fig. 1 shows a snapshot from the input fields of the DSS. The left hand side has the input tables and the Python code can be observed at the right hand side.

The hospital management contacted the authors during March and asked for a schedule of April. They stated that they were used to prepare the schedules of regular shifts, however preparing shifts with the new COVID-19 departments manually was not possible for them. After several iterations, we ended up with schedule for April. Since the time was extremely limited, the schedule was immediately published and implemented. The problems with the premature model(s) (of April) was solved in the May version with several constructive feedbacks from the management. Some important feedbacks can be given as follows. First, the initial model did not employ constraints (10)-(12). Each physician had the same number of COVID-19 shift with the physicians in the same department but there were differences between the COVID-19 shifts of the physicians from different departments. This led to several complaints from the physicians. Therefore we added the constraints in (10)-(12). Second, the management asked to assign physicians from different departments to COVID-19 shifts, hence we added constraint (4), which allows only one physician from a department for COVID-19 shifts. Third, they asked whether the model can handle personal requests or not. Although any request can be employed in the model using constraints, we decided not to incorporate the requests in the model since the authors’ personal experiences (Geçici & Güler, 2020; Güler & Geçici, 2020; Güler et al., 2013) show that once personal requests are incorporated it becomes very hard to manage the process in terms of social affairs. Last, they requested some operational issues. For example, they stated that it was hard for the management (and the physicians) to read the results from Table A2 in appendix. Hence we prepared Table A1 as well. During implementation phase, we didn’t employ the constraint (6) which sets two off-days in a shift since the run-time of the model increases significantly which makes it hard to iterate schedules with the management that asks for urgent schedules in the pandemic period. However we keep the constraint in the model in order to have a general solution. Furthermore, the model was infeasible when $MDD_{ld} = 0$, we set $MDD_{ld} = 1$. Moreover we set $MLD_l = 1$ for all COVID-19 departments as well. Therefore the difference between the maximum and minimum number of COVID-19 shifts was set to one.

We ran our system by using the computer with 8 GB RAM and Intel® Core™ i5-310210U CPU processor. The optimal shift schedule with 81 physicians was obtained in almost a minute (65 s). Since there are 81 physicians and 31 days, the output has a large size. Hence, here we only present a weekly part of the schedule in the appendix. While Table A1 gives list of COVID-19 shifts at the first week, Table A2 presents the shift schedules of the physicians of the first week. The complete schedule can be found in the online appendix.

The resulting number of shifts for each physician are given in Table 4. It can be observed that total shift of each physician in a particular department is in the range of plus or minus one of other physicians. The summary of the workload according to the departments is given in Table 5. Note that even though the MIP model provides equal COVID-19 shifts and regular shifts for each physician, the total number of shifts for physicians in different departments can vary. It turns out that some departments, with the new COVID-19 load, have a significant workload when compared to the others. For example internal medicine physicians have almost 15 shifts whereas the physicians in the pool has less than nine shifts. This is due to the fact that physicians have different specialities, i.e., some are eligible to work in all COVID-19 departments while some are not. Nevertheless, the schedule of May was widely adopted by the management and the physicians and implemented in the hospital.

5. Conclusion and future works

In order to cope with the COVID-19 pandemic, most of the hospitals in Turkey opened new departments like COVID-ICU, COVID-Service, and COVID-Emergency to respond quickly to infected patients. The increased workload made the planning process more important than before. Although institutions are able to generate their regular shift schedules, they needed professional support for this unexpected pandemic period. In this study, we proposed a MIP model and developed a DSS that uses the MIP model to address the problem of scheduling the shifts of physicians in a hospital during COVID-19 pandemic. All of the physicians has to work in COVID-19 departments as well as their own regular departments. Our DSS is able to generate schedules for physicians within almost a minute. The shifts of physicians are distributed evenly and the duration of exposure to the virus is reduced. Thus, while the resulting schedule provides more comfortable working mentally, time is left for rest after intense shifts. In future studies, this structure can be implemented as a web service in order to give access to any hospital that is in need for a help.

CRediT authorship contribution statement

Mehmet Güray Güler: Conceptualization, Methodology, Supervision, Project administration. Ebru Geçici: Software, Validation, Formal analysis, Investigation, Resources, Data curation, Visualization.

Acknowledgement

We are grateful to two anonymous reviewers whose invaluable comments contributed significantly to the final version of the manuscript. We also express our deepest gratitude all healthcare professionals for their efforts during the COVID-19 pandemic.

Appendix A

See Table A1 and A2.
| Table A1 | The COVID-19 shifts. |
|---------|------------------|

| Day | Shift | COVID-ICU | COVID-EMERGENCY | COVID-SERVICE |
|-----|-------|-----------|----------------|---------------|
| May 1 | Internal Medicine Dr.1 | General Surgery Dr.5 | Psychiatry Dr.4 | Orthopedics Dr.2 |
| | | Internal Medicine Dr.5 | 08:00-20:00 | 08:00-16:00 | Radiology Dr.2 |
| | | Cardiology Dr.3 | 08:00-16:00 | Orthopedics Dr.2 | Eye Center Dr.1 |
| | | Neurology Dr.2 | 16:00-24:00 | | Psychiatry Dr.6 |
| | | Cardiology Dr.2 | | | |
| May 2 | Internal Medicine Dr.3 | General Surgery Dr.3 | Orthopedics Dr.7 | X-Group Dr.10 |
| | | Neurology Dr.4 | | | Radiology Dr.4 |
| | | Cardiology Dr.1 | | | Ear, Nose and Throat Disorders Dr.1 |
| | | | | | Eye Center Dr.4 |
| | | | | | Ear, Nose and Throat Disorders Dr.2 |
| | | | | | Radiology Dr.1 |
| May 3 | Internal Medicine Dr.5 | Radiology Dr.5 | X-Group Dr.9 | Orthopedics Dr.1 |
| | | | | | Eye Center Dr.6 |
| | | | | | Ear, Nose and Throat Disorders Dr.3 |
| May 4 | Internal Medicine Dr.5 | Urology Dr.2 | Chest Diseases Dr.2 | Eye Center Dr.1 |
| | | | | | Orthopedics Dr.3 |
| | | | | | Eye Center Dr.7 |
| | | | | | Orthopedics Dr.6 |
| May 5 | Internal Medicine Dr.1 | Eye Center Dr.2 | Psychiatry Dr.2 | Orthopedics Dr.5 |
| | | Cardiovascular Surgery Dr.1 | | | Radiology Dr.3 |
| | | Cardiology Dr.1 | | | Psychiatry Dr.1 |
| | | Neurology Dr.1 | | | |
| | | Cardiology Dr.2 | | | |
| May 6 | Internal Medicine Dr.3 | General Surgery Dr.2 | Eye Center Dr.5 | Radiology Dr.7 |
| | | Neurology Dr.1 | | | Psychiatry Dr.3 |
| | | Brain Surgery Dr.4 | | | X-Group Dr.2 |
| | | Neurology Dr.4 | | | Radiology Dr.6 |
| | | Cardiology Dr.4 | | | X-Group Dr.3 |
| May 7 | General Surgery Dr.3 | X-Group Dr.11 | Ear, Nose and Throat Disorders Dr.2 | Orthopedics Dr.5 |
| | | Internal Medicine Dr.1 | | | Radiology Dr.4 |
| | | Cardiology Dr.3 | | | Psychiatry Dr.5 |
| | | | | | Chest Diseases Dr.1 |
| | | | | | Eye Center Dr.3 |
| | | | | | Radiology Dr.4 |
| | | | | | X-Group Dr.5 |

Table A2
Physicians shift schedule.

| No | Physician/Days | May 1 | May 2 | May 3 | May 4 | May 5 | May 6 | May 7 |
|----|----------------|-------|-------|-------|-------|-------|-------|-------|
| 1  | Orthopedics Dr.1 | COVID-Service | 08:00-20:00 | Regular Shift | 08:00-7:59 | COVID-Emergency | 24:00-08:00 | Regular Shift | 08:00-7:59 |
| 2  | Urology Dr.1 | COVID-Service | 08:00-20:00 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 |
| 3  | Eye Center Dr.1 | COVID-Service | 08:00-20:00 | Regular Shift | 08:00-7:59 | COVID-Emergency | 24:00-08:00 | Regular Shift | 08:00-7:59 |
| 4  | Ear, Nose and Throat Disorders Dr.1 | COVID-Service | 08:00-20:00 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 |
| 5  | General Surgery Dr.1 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 |
| 6  | Radiology Dr.1 | COVID-Service | 08:00-20:00 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 |
| 7  | Psychiatry Dr.1 | Regular Shift | 08:00-7:59 | COVID-Service | 08:00-20:00 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 |
| 8  | Pool Dr.1 | COVID-Service | 08:00-20:00 | COVID-Service | 08:00-20:00 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 |
| 9  | Internal Medicine Dr.1 | COVID-ICU | COVID-ICU | COVID-ICU | COVID-ICU | COVID-ICU | 20:00-08:00 | Regular Shift | 08:00-7:59 |
| 10 | Chest Diseases Dr.1 | Regular Shift | 08:00-20:00 | COVID-ICU | 08:00-20:00 | COVID-ICU | 08:00-20:00 | Regular Shift | 08:00-7:59 |
| 11 | Neurology Dr.1 | Regular Shift | 08:00-7:59 | COVID-ICU | 08:00-20:00 | COVID-ICU | 08:00-20:00 | Regular Shift | 08:00-7:59 |
| 12 | Brain Surgery Dr.1 | COVID-ICU | 08:00-20:00 | Regular Shift | 08:00-7:59 | COVID-ICU | 08:00-20:00 | Regular Shift | 08:00-7:59 |
| 13 | Cardiovascular Surgery Dr.1 | COVID-ICU | 20:00-08:00 | Regular Shift | 08:00-7:59 | COVID-ICU | 08:00-20:00 | Regular Shift | 08:00-7:59 |
| 14 | Cardiology Dr.1 | COVID-ICU | 20:00-08:00 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 | Regular Shift | 08:00-7:59 |
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