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Research Article

Pharmacy Duty Scheduling Problem: Gümüşhane Case

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ABSTRACT

In the Turkish Healthcare System, pharmacies are an important echelon of the drug supply chain. The pharmacy on duty practice ensures that the demand for drugs and similar medical supplies is met 24/7. The duty pharmacy scheduling problem aims to satisfy the customers and the pharmacists without violating the regulations while determining the duty sequence of the pharmacies in a certain planning period. This study handles the duty pharmacy scheduling problem of Gümüşhane City Center where 13 pharmacies operate. In the current system, the representative pharmacist prepares the duty schedule manually. The planning period is divided into subsets, and pharmacies are assigned to the duties in each subset respectively in such the number of duties of each pharmacy in the subsets is as equal as possible. The managerial problem of the case is that the duty frequency of each pharmacy is variable in the manual schedule and pharmacists perceive this as an unfairness. Because pharmacists expect to be on duty 1 in 13 days. We propose a mathematical model that adopts the fixed duty frequency and the inheritance of duty distribution. We test the model according to the 2020 calendar and compare model results with the real duty schedule belong to 2020 using the 2019 distribution of pharmacies. The comparison and test results show that the duties are distributed as fairly as possible and the turn of each pharmacy is repeated once every 13 days. The contribution of this study is that it introduces innovative components to the pharmacy duty scheduling problem, offers practical policy recommendations, and provides a case-specific example to limited PDS literature.

Keywords: Pharmacy Duty Scheduling, Integer Programming, The Fixed Duty Frequency, The Inheritance of Duty Distribution

1. Introduction

The drug supply chain is a critical issue for any healthcare system. Unrestricted access to drugs can lead to improper and unnecessary use, thereby deteriorating public health. On the other hand, strict control or prohibition may fail treatments and high demand in healthcare facilities. Policymakers try to control access to drugs through various regulations. In the Turkish Healthcare System, only pharmacies are authorized for a drug sale. Besides selling drugs, the role of a health consultant makes pharmacies an important component of the system. Pharmacies are subject to the Regional Chamber of Pharmacists to which they are affiliated. Ensuring continuity of the drug supply 24/7 is among the tasks of the Chamber. For this purpose, it regulates the working hours of pharmacies and makes sure that a sufficient number of pharmacies are on duty to cover the region in the off-hour period. The pharmacy on duty continues to serve from the end to the beginning of the working hours on weekdays and Saturdays, and also all day on days such as Sundays and Bank Holidays, based on a schedule.

Although regulations exist, the process of identifying the pharmacy on duty remains a black box, as it is not defined how to combine stakeholder-based factors such as accessibility, capacity, and proximity to each other of pharmacies. The decision on the pharmacy on duty should satisfy the two key stakeholders of the system: the pharmacist and the customer. The pharmacist, who operates the pharmacy, expects the schedule to be as fair as possible and the maximum distance between the duty pharmacies, since being on duty is economically more profitable. The customer, who is a patient or someone who needs a medical item, wants to reach the pharmacy on duty with the least effort to meet the urgent need for medical supplies as soon as possible. The schedule is widely prepared by representative pharmacists manually. The handicap of manual scheduling is that the quality of the schedule varies depending on the judgment and experience of the representative.

Operations Research (OR) supports decision-makers from different disciplines to make impersonal decisions using analytical methods. The OR literature provides effective solutions to healthcare management challenges such as planning (Swisher, Jacobson, Jun, & Balci, 2001), performance measurement (Varela, de Martins, & Fávero, 2010), location (Kanuganti, Sarkar, Singh, & Arkatkar, 2015), patient flow (Jiang & Giachetti, 2008), and scheduling (Adan, Bekkers, Dellaert, Vissers, & Yu, 2009) with techniques such as integer programming (Brunner, Bard, & Kolisch, 2009), simulation (Abo-Hamad & Arisha, 2013) and multi-criteria decision making (Dursun, Karsak, & Karadayi, 2011). Kahraman & Topcu (2018) collect OR techniques used in healthcare management and Tuzun & Topcu (2018) present a detailed taxonomy. The representative's challenge is handled as Pharmacy Duty Scheduling (PDS) in the scope of OR. PDS focuses on satisfying well-defined constraints of both stakeholders and regulations, and also optimizing the objectives of decision-maker when determining the duty sequence of pharmacies within a certain planning period.

The PDS has scarce literature with two branches: solution-oriented and case-specific. Solution-oriented studies focus on computing acceptable solutions with heuristic methods in cases where exact solution methods to large-scale PDS problems are inoperative. Variable Neighborhood Search Algorithm (Kocatürk & Özpeynirci, 2014), Tabu Search Algorithm (Özpeynirci & Ağlamaz, 2016), Branch and Price Algorithm (Ceyhan & Özpeynirci, 2016) are recommended methods in the literature for large-scale PDS problems.

The case-specific PDS problems address real-life challenges and include soft and hard constraints depending on the attribute of the case. In a feasible solution, hard constraints must be satisfied, and soft constraints should be fulfilled as much as possible. For example, the assignment of at least one pharmacy on duty is a hard constraint, whereas the distribution of duties to pharmacies as equally as possible is a soft constraint. Ozgur et al. (2009) developed a web-based application for the PDS problem of Ankara Pharmacist Association (APA). The application utilizes a stochastic optimization approach that uses a Simulated Annealing (SA) algorithm and satisfies the requirements of the APA. Remarkable requirements are the maximum distance between pharmacies on duty and the fair schedule. Uncu et al. (2018) proposed a distance restricted maximal covering location model for the PDS problem of Adana Chamber of Pharmacists. The objective of the study is fair scheduling, subject to a minimum distance between pharmacies on duty. Fair scheduling and maximizing the distance between duty pharmacies, which are commonly considered, are major characteristics of the PDS problem.

This study deals with the PDS problem of Gümüşhane City Center. The special situation of the case mentioned in Section 2 reduces the PDS only to a fair schedule. The critical notes from the interview with pharmacists are as follows; (i) The duty schedule is prepared annually by the representative pharmacist manually and published monthly, (ii) Pharmacies' duty sequences are followed in 3 subsets: Weekdays, Sundays, and Bank Holidays, (iii) The goal is to assign an equal number of duties to each pharmacy in each subset, (iv) The variable frequency of duties is the biggest complaint of pharmacists. To overcome mentioned complaint, we propose a mathematical model that adopts the fixed duty frequency and also the heredity of duty distribution to provide fair distribution. Then we analyze the impact of the subset configuration on the schedule fairness. We also present a comparison model results with the real duty list belong to 2020 using the 2019 distribution of pharmacies.

The remainder of the study is organized as follows. Section 2 introduces the case and identifies the problem. Mathematical formulations and analyses, respectively, are in Sections 3 and 4. Section 5 contains the conclusions and policy recommendations.

2. Gümüşhane Case

In this section, we give information about the case and highlight the problem. Gümüşhane is a small city with only 13 pharmacies in the city center. While 10 of 13 are located on the same street in a side by side and/or opposite position, 3 of 13 are all together at a distance of approximately 1 km from others. Figure 1 shows the location of the pharmacies. The maximum distance between pharmacies (E5 and E12 pharmacies) is about 1.5 km. As the pharmacies are few and too close to each other, the city center is considered as a single region and only one pharmacy is on duty each day. From a different viewpoint, the special situation of the city can be emphasized as follows. Let's imagine that two pharmacies are on duty every day in the Gümüşhane. In this setting, the distance between pharmacies on duty is too short to cause idle service delivery, and also the maximum distance is even less than the minimum distance (1.6 km) accepted in Uncu et al. (2018).

In cities with many high population zones, more than one pharmacy is on duty to spread and satisfy demand, and to meet the needs of customers with the least effort, taking account of their distance from each other. However, Gümüşhane city center does not have a population density that would require more than one pharmacy on duty. These details minify the influence of the customers on the decision. Fair scheduling remains the only goal of the PDS of the case.

Figure 1. Pharmacy locations

The planning period is one year and consists of three subsets according to regulations: Weekdays (W), Sundays (S), and Bank Holidays (BH). For instance, Saturday, October 31, 2020 is in W, Sunday, November 1, 2020 is in S, Thursday, 29 October 2020 (Republic Day in Turkey) is in BH. In subset W, the pharmacy on duty runs approximately 16 hours from the end of working hours to the beginning, and 24 hours in the subsets S and BH. According to the 2020 calendar data, the distribution of the duties to the subset is as follows: W:301, S:49, BH:16.

In current practice, the representative pharmacist follows a turn-based approach for the fair distribution of days in each subset to pharmacies in such a way that the same pharmacy will not be on duty on consecutive days. Although the calendar day order of the days in the subsets W and S are in a regular pattern, the days in the BH are irregular. This situation leads to a fluctuation in the duty frequency in the preparation of a fair schedule. Due to the economic worth of the duty days, the variability of duty frequency creates conflict between pharmacies. While pharmacists expect to be on duty 1 in 13 days, with a manual schedule the duty frequency may decrease to 1 in 9-10 days. Mainly the underlying cause of this is the effort to distribute the duties equally, but the fair distribution may not be possible within a single planning period, only by taking into account multiple planning periods. Pharmacists can accept the allocation of fair duty distribution in the long term because calendar days can not be changed, whereas the variable duty frequency is not acceptable as it causes a difference in earnings in the short term. Therefore, we handle the fixed duty frequency as a hard constraint.

The fixed frequency approach implies that each pharmacy will be on duty in a locked turn during the planning period. This approach causes pharmacies to have a different number of duties in the same subset due to the irregularity of the days in the BH subset. Since the 24-hour duty is more profitable than the 16-hour duty, the unbalanced sharing causes conflict between pharmacies. The decision-maker can compensate for this in the next period and allocate balanced sharing with a holistic perspective. This opportunity eliminates obstacles to the fixed duty frequency approach, as long as the inheritance of the duty distribution is taken into account. The inheritance of the duty distribution is realized by including the duty distribution of each subset from the previous periods to the current planning. Also, it facilitates rescheduling in events that interrupt the planning period, such as opening a new pharmacy or closing an existing pharmacy.

When the variability in duties frequencies is interpreted as a symptom, it can be seen that the main source of the problem is subsets. The current subset configuration is based on the attribute of the calendar day but the duration of the duties is the main attribute that distinguishes the duty days. The duties in the S and BH subsets can be combined as they last for a full day. Two subsets based on duty duration are more valid. Decision-makers may explain more easily that two different duty sequences are followed for both subsets as the reason for the variability in duty frequencies.

3. Problem Formulation

In this section, we present the mathematical formulation of the problem.

Sets and Indices

$E: \{E_1, E_2, \dots, E_{13}\}$: Set of Pharmacies, $e \in E$

$G: \{1,2,\dots,365\}$: Set of Planning Period, $g \in G$

$T: \{W, S, BH\}$: Set of Subsets of Planning Period, $t \in T$

Parameters

T_g : Indicates in which subset day g is.

$d_{e,t}$: Number of duties in the subset t of pharmacy e in the previous planning period.

Decision Variables

$x_{e,g}$: $\begin{cases} 1, & If\ the\ pharmacy\ e\ is\ on\ duty\ on\ day\ g \\ 0, & Otherwise \end{cases}$

$y_{e,t}$: Number of duties under subset t of pharmacy e

$y_t^{\max}$: The maximum number of duties in a pharmacy's subset t

Objective Function

$$Min\ Z = \sum_{t \in T} y_t^{\max} \tag{1}$$

Constraints

$$\sum_{e \in E} x_{e,g} = 1 \qquad \forall\, g \in G \tag{2}$$

$$\sum_{g\in G:T_g=t} x_{e,g} + d_{e,t} = y_{e,t} \qquad \forall\, e \in E, t \in T \qquad (3)$$

$$y_{e,t} \le y_t^{max} \qquad \forall\, e \in E, t \in T \qquad (4)$$

$$\sum_{g'=1}^{|E|} x_{e,g+g'} = 1 \qquad \forall\, e \in E, g \in \{1, \dots, |G| - |E|\} \qquad (5)$$

The objective function (1) ensures that minimize the maximum number of duties of a pharmacy in each subset. Constraint (2) allows only one pharmacy to be on duty in a day. (3) calculates the number of duties in each subset of each pharmacy by including the previous planning period. The inheritance of the duty distribution is provided by this constraint. (4) limits the maximum number of duties of a pharmacy in each subset. (5) guarantees that each pharmacy is on duty in a cycle and once per cycle. The pharmacy number determines the cycle length. This constraint also prevents a pharmacy from being on duty on consecutive days. The combination of (1) and (4) reflects a min-max approach, ensuring the distribution of duties as equally as possible.

Note that the solution can be sought with the Goal Programming approach or Pareto Optimal solution with the multi-objective formulation. However, the decision problem discussed is more suitable for the described biobjective modeling.

4. Analysis

This section aims to test the behavior of the model according to the 2020 calendar data and to observe the effect of changing in subset configurations. We perform all tests in the Python/Gurobi modeling environment with a 3.5 GHz i5-8250U processor and 12 GB RAM. We measure the quality of the schedule with the standard deviation of the duty distribution, and we call it the fairness score. The fairness score represents the difference in pharmacy duty numbers and it is desirable to be close to zero.

We use a test platform consisting of two stages illustrated in Figure 2. The first stage acts as the previous period and the second stage represents the current period. In the first stage, the model runs with parameter d that is null. The inheritance of the duty distribution is provided by the parameter d. In the second stage, the ability of the model is tested according to parameter d that is full.

Expectations in the results are as follows: i) The low fairness score, ii) The fixed duty frequency, iii) Decrease in the fairness score in a holistic view.

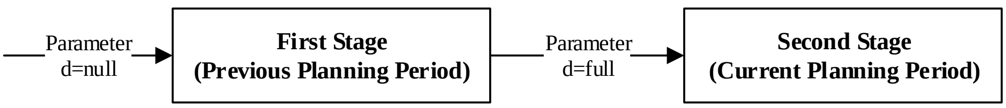

Figure 2. Schema of the testing platform

	First Stage					Second Stage					Cumulative			
Pharmacy	W	S	BH	Total	Turn	W	S	BH	Total	Turn	W	S	BH	Total
E1	23	4	1	28	8	24	3	1	28	7	47	7	2	56
E2	23	4	1	28	11	24	3	2	29	2	47	7	3	57
E3	24	4	0	28	13	23	4	1	28	3	47	8	1	56
E4	24	3	2	29	2	23	4	1	28	11	47	7	3	57
E5	22	4	2	28	5	24	4	0	28	12	46	8	2	56
E6	24	4	1	29	1	22	4	2	28	4	46	8	3	57
E7	22	4	2	28	6	24	4	0	28	13	46	8	2	56
E8	24	3	1	28	9	22	4	2	28	5	46	7	3	56
E9	24	3	1	28	7	22	4	2	28	6	46	7	3	56
E10	24	4	0	28	12	22	4	2	28	10	46	8	2	56
E11	22	4	2	28	4	23	4	1	28	8	45	8	3	56
E12	23	4	1	28	3	24	3	1	28	9	47	7	2	56
E13	22	4	2	28	10	24	4	1	29	1	46	8	3	57
Fairness Score	0.86	0.42	0.70	0.36		0.86	0.42	0.70	0.36		0.61	0.50	0.63	0.46
Average	0.66					0.66					0.58			
Values in the columns W, S, BH, and Total show the number of duties.														
The turn column shows the fixed duty sequence of the pharmacy.														
Fairness Score represents the standard deviation of the relevant column.														

Table 1. Test Results of the Model

The annual duty schedule obtained at the end of the second stage is in the appendix[1]. Table 1 shows the number of duties in each subset and the duty sequence. When the duty schedule is examined, it is seen that the duty sequence (Turn column in Table 1) in the first stage is followed, the model has implemented the fixed duty frequency. The results in Table 1 have a low fairness score. The reason for the score not being 0 is that the number of days in the subsets is not proportional to the number of pharmacies and the pharmacies have the fixed on duty sequence throughout the planning period. The average fairness score of the subsets is 0.66 in the first stage, 0.66 in the second stage, and 0.58 in the cumulative results. The low score in the cumulative results indicates that the model is successful in balancing. Test results show that the model meets expectations. We can claim that the fixed duty frequency and the inheritance of duty distribution approaches eliminate the main problem of the case and automated scheduling can replace manual scheduling. Also, we analyze the effect of subset settings on the schedule. Table 2 displays the test subset configurations. S1 is the basic subset configuration of the problem. In S2, S and BH subsets are combined and the number of subsets is reduced to 2. Underlying the idea of reducing subsets lies the similarities in the duration of duties. On the days in subset W, the duties last about 16 hours from the end of working hours to the beginning (18:00 → 09:00), whereas the days in the S and BH subsets last for a full day (09:00→09:00, 24 hours). In S2, W covers 16-hour duty days and S includes 24-hour duty days.

	W	S	BH
S1	301	49	16
S2	301	65	-
The values show the number of duties in each subset.			

Table 2. Subsets Configurations

[1] For the relevant readers, the average calculation time of the two stages is approximately 2 seconds.

Since the results of S1 are the same as Table 1, Table 3 shows the number of duties in each subset and the duty sequence, according to S2. The model is consistent to obtain a fair schedule with the low fairness score and to balance the number of duties in subsets in both configurations by changing the duty sequence, see E2, E3, E4 as examples. The duty distribution of S1 and S2 indicates that the model is not sensitive to data, stable, and also can handle different subset configurations.

	First Stage				Second Stage				Cumulative		
Pharmacy	**W**	**S**	**Total**	**Turn**	**W**	**S**	**Total**	**Turn**	**W**	**S**	**Total**
E1	24	5	29	2	23	5	28	8	47	10	57
E2	23	5	28	8	24	5	29	1	47	10	57
E3	23	5	28	11	23	5	28	11	46	10	56
E4	22	6	28	5	24	4	28	7	46	10	56
E5	24	5	29	1	23	5	28	3	47	10	57
E6	24	4	28	9	22	6	28	6	46	10	56
E7	24	4	28	7	22	6	28	4	46	10	56
E8	24	4	28	12	22	6	28	5	46	10	56
E9	22	6	28	4	24	4	28	9	46	10	56
E10	24	4	28	13	22	6	28	10	46	10	56
E11	23	5	28	3	24	5	29	2	47	10	57
E12	22	6	28	10	24	4	28	12	46	10	56
E13	22	6	28	6	24	4	28	13	46	10	56
Fairness Score	**0.86**	**0.78**	**0.36**		**0.86**	**0.78**	**0.36**		**0.46**	**0.00**	**0.46**
Average	**0.82**				**0.82**				**0.23**		

Values in the columns W, S, and Total show the number of duties.
The turn column shows the pharmacy's fixed duty sequence.
Fairness Score represents the standard deviation of the relevant column.

Table 3. Test Results of S2

In the comparison of the cumulative fairness scores of S1 and S2, it is seen that the results of S2 reflect fairness better than S1 and the confusing minor differences in S1 are not in S2.

If manual scheduling continues, the S2 configuration is a more practical option to a fair schedule. In manual scheduling based on S2, even if the frequency of duty varies, believing that this is due to two different sequences for the two subsets and making sure that they do not have a financial loss due to the total number of duties in both subsets is the same makes the situation more acceptable to pharmacists.

4.1. Comparison of Model Results with the Real Duty List

In this part of the study, we compare the model results for 2020 with the real duty list of 2020 by using the 2019 duty distributions of pharmacies. Before the comparison, we displayed the variability of the duty frequency, which constitutes the motivation for the problem, in Table 4. The links to real duty lists are in footnotes[2].

[2] Duty Pharmacy Lists
2019 January, February, March: https://www.trabzoneczaciodasi.org.tr/duyuru/31122018-gumushane-ocak-subat-mart-nobet-listeleri-4559
2019 April, May, June: https://www.trabzoneczaciodasi.org.tr/duyuru/gumushane-ili-nisan-mayis-haziran-2019-aylarina-ait-nobet-listesi-4647
2019 July, August, September: https://www.trabzoneczaciodasi.org.tr/duyuru/28062019-gumushane-merkez-temmuz-agustos-eylul-2019-nobet-listesi-4705
2019 October, November, December: https://www.trabzoneczaciodasi.org.tr/duyuru/30092019-gumushane-merkez-ekim-kasim-aralik-2019-nobet-listeleri-4749
2020 January, February, March: https://www.trabzoneczaciodasi.org.tr/duyuru/27122019-gumushane-merkez-ocak-subat-mart-2020-nobet-listesi-4847
2020 April, May, June: https://www.trabzoneczaciodasi.org.tr/duyuru/26032020-gumushane-ili-nisan-mayis-haziran-2020-nobetleri-4984
2020 July, August, September: https://www.trabzoneczaciodasi.org.tr/duyuru/29062020-gumushane-merkez-temmuz-agustos-eylul-2020-nobet-listeleri-5153
2020 October, November, December: https://www.trabzoneczaciodasi.org.tr/duyuru/28092020-gumushane-ili-ekim-kasim-aralik-2020-nobetleri-5241

	2019 Duty List				2020 Duty List			
Pharmacy	**Max**	**Min**	**Average**	**Std. Dev.**	**Max**	**Min**	**Average**	**Std. Dev.**
Derman	25	5	13,58	5,82	24	5	12,71	4,16
Elif	29	5	13,33	5,52	28	7	13,73	4,92
Gümüşhane	27	7	13,73	5,10	21	6	12,86	3,12
Hayat	23	6	13,19	4,33	21	5	12,36	3,88
Işık	24	4	13,50	4,81	27	5	12,79	5,16
Karaca	25	5	12,50	5,47	28	6	13,56	5,25
Merkez	24	5	12,11	5,17	31	4	13,81	5,54
Özkan	29	6	13,00	5,06	24	6	13,15	4,20
Sağlık	23	6	13,15	4,60	19	5	12,86	3,34
Sinem	26	6	12,71	4,63	21	6	12,70	3,99
Şifa	28	6	12,68	5,40	24	4	12,96	4,76
Yalçın	37	6	13,07	6,01	24	4	12,29	5,09
Yüce	22	5	12,39	4,39	27	8	13,26	4,31
Average	26,31	5,54	13,00	5,10	24,54	5,46	13,00	4,44
	Max: The pharmacy's maximum number of days between duties **Min:** The pharmacy's minimum number of days between duties **Average:** Average number of days between the pharmacy's duties **Std. Dev.:** The standard deviation of the number of days between the pharmacy's duties							

Table 4. The duty frequencies of pharmacies for 2019 and 2020.

The difference between the maximum and minimum duty frequencies justifies the complaints of pharmacists. For example, the Yalçın Pharmacy in 2019, after its duty on 14 July 2019, its next duty took place 37 days later on 20 August 2019. In 2020, Şifa Pharmacy is an opposite example. After its duty on 31 May 2020, its next duty took place 4 days later on 4 June 2020. Although the average duty frequency of pharmacies is around 1 in 13 days, standard deviations greater than 0 reveals variability. The current duty distribution policy does not meet the expectations as stated in the motivation of the problem.

The pharmacy duty distributions in 2019 and 2020, which were prepared manually by the representative pharmacist, are shown in Table 5. The fairness scores in the 2020 duty distribution show an improvement in the S subset but a worsening in the W and BH subsets. The cumulative distribution demonstrates that the unfairness in 2019 was not tolerated in 2020.

When the 2020 duty distributions of pharmacies are evaluated keeping in mind the duty variability shown in Table 4, it is visible that manual scheduling is far from satisfying the pharmacies' expectations.

	Real-2019				Real-2020				Cumulative			
Pharmacy	**W**	**S**	**BH**	**Total**	**W**	**S**	**BH**	**Total**	**W**	**S**	**BH**	**Total**
Derman	23	4	0	27	24	4	1	29	47	8	1	56
Elif	23	4	1	28	21	4	2	27	44	8	3	55
Gümüşhane	22	4	1	27	24	4	1	29	46	8	2	56
Hayat	23	3	1	27	24	4	1	29	47	7	2	56
Işık	22	4	1	27	24	4	1	29	46	8	2	56
Karaca	24	3	2	29	22	3	1	26	46	6	3	55
Merkez	23	5	1	29	22	4	1	27	45	9	2	56
Özkan	23	4	1	28	24	4	0	28	47	8	1	56
Sağlık	23	4	1	28	24	4	1	29	47	8	2	57
Sinem	24	4	1	29	23	3	2	28	47	7	3	57
Şifa	23	4	2	29	24	4	0	28	47	8	2	57
Yalçın	24	3	1	28	23	3	3	29	47	6	4	57
Yüce	24	4	1	29	22	4	2	28	46	8	3	57
Fairness Score	**0,66**	**0,53**	**0,47**	**0,83**	**1,03**	**0,42**	**0,80**	**0,95**	**0,91**	**0,84**	**0,82**	**0,70**
Average	**0,56**				**0,75**				**0,86**			

Table 5. The distribution of the pharmacies in the 2019 and 2020

While the proposed model enables pharmacies to be on duty at a fixed frequency, it tries to balance cumulative duty distribution. For this, it needs the distribution of duties from the previous period. Using the 2019 duty distribution as the parameter d, the model result of 2020 allows us to measure model performance with the real duty list of 2020. Table 6 shows the duty distribution of the model for 2020 using the 2019 duty distribution and the duty frequency of pharmacies in this distribution.

	Model-2020				Cumulative (Real-2019 + Model-2020)				The duty frequencies of pharmacies for Model-2020			
Pharmacy	**W**	**S**	**BH**	**Total**	**W**	**S**	**BH**	**Total**	**Max**	**Min**	**Average**	**Std. Dev.**
Derman	23	4	1	28	46	8	1	55	13	13	13	0
Elif	24	3	1	28	47	7	2	56	13	13	13	0
Gümüşhane	24	4	0	28	46	8	1	55	13	13	13	0
Hayat	24	4	0	28	47	7	1	55	13	13	13	0
Işık	23	4	1	28	45	8	2	55	13	13	13	0
Karaca	23	4	1	28	47	7	3	57	13	13	13	0
Merkez	24	3	1	28	47	8	2	57	13	13	13	0
Özkan	24	3	2	29	47	7	3	57	13	13	13	0
Sağlık	22	4	2	28	45	8	3	56	13	13	13	0
Sinem	22	4	2	28	46	8	3	57	13	13	13	0
Şifa	24	4	1	29	47	8	3	58	13	13	13	0
Yalçın	22	4	2	28	46	7	3	56	13	13	13	0
Yüce	22	4	2	28	46	8	3	57	13	13	13	0
Fairness Score	**0,86**	**0,42**	**0,70**	**0,36**	**0,72**	**0,49**	**0,82**	**0,97**				
Average	**0,66**				**0,68**							

Table 6. Model results and the duty frequencies for 2020

When the Real-2020 results in Table 5 and the Model-2020 results in Table 6 are compared, it is seen that the model provides a fairer distribution. In addition, the cumulative distribution shows that unfairness in 2019 can be tolerated in 2020, the average fairness score has increased considerably. The improvement in the fairness score and the stability in duty frequency shows that the model meets the expectations of the pharmacies.

5. Conclusion and Policy Recommendation

In this study, we handle the duty scheduling problem of pharmacies in Gümüşhane City Center. While the PDS literature focuses on combining the conflicting interests of the customers and pharmacist stakeholders, this study focused only on the satisfaction of pharmacists due to the special situation of the Gümüşhane. This specialty causes a single pharmacy to be on duty every day and reduces the problem to only ensuring a fair distribution of duties. The factor that affects the satisfaction of pharmacists is that the frequency of the duty is variable. While the decision-maker manually assigned the duties in each subset to the pharmacies to create a fair schedule, it cannot prevent the duty day from converging.

The proposed model can distribute the duties as fairly as possible, taking into account the previous duty distribution, provided that it ensures a fixed duty sequence. The results of the analysis verify the behavior of the model. Automatic scheduling allows the decision-maker to create schedules that are quick and do not require accuracy control.

In the current practice, the planning period is divided into three subsets according to the attribute of the days. However, the days of duties for pharmacists differ according to the duration of the duty. From this point of view, it is reasonable to divide the planning period into two subsets, which last for 16 hours and 24 hours. When the distribution of the duties was examined using the two subset configurations, it was found that a fairer schedule was obtained. Accordingly, a two-subset approach based on duty duration can be offered to policymakers as a recommendation.

The contributions of the study are that it provides a case-specific example of the limited PDS literature. Also, the factors considered in the study have the potential to be a solution for the problems faced by future researchers and decision-makers.

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Appendix

A-1 January-April Duty Schedule

January	Duty	February	Duty	March	Duty	April	Duty
Wednesday, January 1, 2020	E6	Saturday, February 1, 2020	E7	Sunday, March 1, 2020	E8	Wednesday, April 1, 2020	E6
Thursday, January 2, 2020	E4	Sunday, February 2, 2020	E9	Monday, March 2, 2020	E13	Thursday, April 2, 2020	E4
Friday, January 3, 2020	E12	Monday, February 3, 2020	E1	Tuesday, March 3, 2020	E2	Friday, April 3, 2020	E12
Saturday, January 4, 2020	E11	Tuesday, February 4, 2020	E8	Wednesday, March 4, 2020	E10	Saturday, April 4, 2020	E11
Sunday, January 5, 2020	E5	Wednesday, February 5, 2020	E13	Thursday, March 5, 2020	E3	Sunday, April 5, 2020	E5
Monday, January 6, 2020	E7	Thursday, February 6, 2020	E2	Friday, March 6, 2020	E6	Monday, April 6, 2020	E7
Tuesday, January 7, 2020	E9	Friday, February 7, 2020	E10	Saturday, March 7, 2020	E4	Tuesday, April 7, 2020	E9
Wednesday, January 8, 2020	E1	Saturday, February 8, 2020	E3	Sunday, March 8, 2020	E12	Wednesday, April 8, 2020	E1
Thursday, January 9, 2020	E8	Sunday, February 9, 2020	E6	Monday, March 9, 2020	E11	Thursday, April 9, 2020	E8
Friday, January 10, 2020	E13	Monday, February 10, 2020	E4	Tuesday, March 10, 2020	E5	Friday, April 10, 2020	E13
Saturday, January 11, 2020	E2	Tuesday, February 11, 2020	E12	Wednesday, March 11, 2020	E7	Saturday, April 11, 2020	E2
Sunday, January 12, 2020	E10	Wednesday, February 12, 2020	E11	Thursday, March 12, 2020	E9	Sunday, April 12, 2020	E10
Monday, January 13, 2020	E3	Thursday, February 13, 2020	E5	Friday, March 13, 2020	E1	Monday, April 13, 2020	E3
Tuesday, January 14, 2020	E6	Friday, February 14, 2020	E7	Saturday, March 14, 2020	E8	Tuesday, April 14, 2020	E6
Wednesday, January 15, 2020	E4	Saturday, February 15, 2020	E9	Sunday, March 15, 2020	E13	Wednesday, April 15, 2020	E4
Thursday, January 16, 2020	E12	Sunday, February 16, 2020	E1	Monday, March 16, 2020	E2	Thursday, April 16, 2020	E12
Friday, January 17, 2020	E11	Monday, February 17, 2020	E8	Tuesday, March 17, 2020	E10	Friday, April 17, 2020	E11
Saturday, January 18, 2020	E5	Tuesday, February 18, 2020	E13	Wednesday, March 18, 2020	E3	Saturday, April 18, 2020	E5
Sunday, January 19, 2020	E7	Wednesday, February 19, 2020	E2	Thursday, March 19, 2020	E6	Sunday, April 19, 2020	E7
Monday, January 20, 2020	E9	Thursday, February 20, 2020	E10	Friday, March 20, 2020	E4	Monday, April 20, 2020	E9
Tuesday, January 21, 2020	E1	Friday, February 21, 2020	E3	Saturday, March 21, 2020	E12	Tuesday, April 21, 2020	E1
Wednesday, January 22, 2020	E8	Saturday, February 22, 2020	E6	Sunday, March 22, 2020	E11	Wednesday, April 22, 2020	E8
Thursday, January 23, 2020	E13	Sunday, February 23, 2020	E4	Monday, March 23, 2020	E5	Thursday, April 23, 2020	E13
Friday, January 24, 2020	E2	Monday, February 24, 2020	E12	Tuesday, March 24, 2020	E7	Friday, April 24, 2020	E2
Saturday, January 25, 2020	E10	Tuesday, February 25, 2020	E11	Wednesday, March 25, 2020	E9	Saturday, April 25, 2020	E10
Sunday, January 26, 2020	E3	Wednesday, February 26, 2020	E5	Thursday, March 26, 2020	E1	Sunday, April 26, 2020	E3
Monday, January 27, 2020	E6	Thursday, February 27, 2020	E7	Friday, March 27, 2020	E8	Monday, April 27, 2020	E6
Tuesday, January 28, 2020	E4	Friday, February 28, 2020	E9	Saturday, March 28, 2020	E13	Tuesday, April 28, 2020	E4
Wednesday, January 29, 2020	E12	Saturday, February 29, 2020	E1	Sunday, March 29, 2020	E2	Wednesday, April 29, 2020	E12
Thursday, January 30, 2020	E11			Monday, March 30, 2020	E10	Thursday, April 30, 2020	E11
Friday, January 31, 2020	E5			Tuesday, March 31, 2020	E3		

A-2 May-August Duty Schedule

May	Duty	June	Duty	July	Duty	August	Duty
Friday, May 1, 2020	E5	Monday, June 1, 2020	E13	Wednesday, July 1, 2020	E6	Saturday, August 1, 2020	E7
Saturday, May 2, 2020	E7	Tuesday, June 2, 2020	E2	Thursday, July 2, 2020	E4	Sunday, August 2, 2020	E9
Sunday, May 3, 2020	E9	Wednesday, June 3, 2020	E10	Friday, July 3, 2020	E12	Monday, August 3, 2020	E1
Monday, May 4, 2020	E1	Thursday, June 4, 2020	E3	Saturday, July 4, 2020	E11	Tuesday, August 4, 2020	E8
Tuesday, May 5, 2020	E8	Friday, June 5, 2020	E6	Sunday, July 5, 2020	E5	Wednesday, August 5, 2020	E13
Wednesday, May 6, 2020	E13	Saturday, June 6, 2020	E4	Monday, July 6, 2020	E7	Thursday, August 6, 2020	E2
Thursday, May 7, 2020	E2	Sunday, June 7, 2020	E12	Tuesday, July 7, 2020	E9	Friday, August 7, 2020	E10
Friday, May 8, 2020	E10	Monday, June 8, 2020	E11	Wednesday, July 8, 2020	E1	Saturday, August 8, 2020	E3
Saturday, May 9, 2020	E3	Tuesday, June 9, 2020	E5	Thursday, July 9, 2020	E8	Sunday, August 9, 2020	E6
Sunday, May 10, 2020	E6	Wednesday, June 10, 2020	E7	Friday, July 10, 2020	E13	Monday, August 10, 2020	E4
Monday, May 11, 2020	E4	Thursday, June 11, 2020	E9	Saturday, July 11, 2020	E2	Tuesday, August 11, 2020	E12
Tuesday, May 12, 2020	E12	Friday, June 12, 2020	E1	Sunday, July 12, 2020	E10	Wednesday, August 12, 2020	E11
Wednesday, May 13, 2020	E11	Saturday, June 13, 2020	E8	Monday, July 13, 2020	E3	Thursday, August 13, 2020	E5
Thursday, May 14, 2020	E5	Sunday, June 14, 2020	E13	Tuesday, July 14, 2020	E6	Friday, August 14, 2020	E7
Friday, May 15, 2020	E7	Monday, June 15, 2020	E2	Wednesday, July 15, 2020	E4	Saturday, August 15, 2020	E9
Saturday, May 16, 2020	E9	Tuesday, June 16, 2020	E10	Thursday, July 16, 2020	E12	Sunday, August 16, 2020	E1
Sunday, May 17, 2020	E1	Wednesday, June 17, 2020	E3	Friday, July 17, 2020	E11	Monday, August 17, 2020	E8
Monday, May 18, 2020	E8	Thursday, June 18, 2020	E6	Saturday, July 18, 2020	E5	Tuesday, August 18, 2020	E13
Tuesday, May 19, 2020	E13	Friday, June 19, 2020	E4	Sunday, July 19, 2020	E7	Wednesday, August 19, 2020	E2
Wednesday, May 20, 2020	E2	Saturday, June 20, 2020	E12	Monday, July 20, 2020	E9	Thursday, August 20, 2020	E10
Thursday, May 21, 2020	E10	Sunday, June 21, 2020	E11	Tuesday, July 21, 2020	E1	Friday, August 21, 2020	E3
Friday, May 22, 2020	E3	Monday, June 22, 2020	E5	Wednesday, July 22, 2020	E8	Saturday, August 22, 2020	E6
Saturday, May 23, 2020	E6	Tuesday, June 23, 2020	E7	Thursday, July 23, 2020	E13	Sunday, August 23, 2020	E4
Sunday, May 24, 2020	E4	Wednesday, June 24, 2020	E9	Friday, July 24, 2020	E2	Monday, August 24, 2020	E12
Monday, May 25, 2020	E12	Thursday, June 25, 2020	E1	Saturday, July 25, 2020	E10	Tuesday, August 25, 2020	E11
Tuesday, May 26, 2020	E11	Friday, June 26, 2020	E8	Sunday, July 26, 2020	E3	Wednesday, August 26, 2020	E5
Wednesday, May 27, 2020	E5	Saturday, June 27, 2020	E13	Monday, July 27, 2020	E6	Thursday, August 27, 2020	E7
Thursday, May 28, 2020	E7	Sunday, June 28, 2020	E2	Tuesday, July 28, 2020	E4	Friday, August 28, 2020	E9
Friday, May 29, 2020	E9	Monday, June 29, 2020	E10	Wednesday, July 29, 2020	E12	Saturday, August 29, 2020	E1
Saturday, May 30, 2020	E1	Tuesday, June 30, 2020	E3	Thursday, July 30, 2020	E11	Sunday, August 30, 2020	E8
Sunday, May 31, 2020	E8			Friday, July 31, 2020	E5	Monday, August 31, 2020	E13

A-3 September-December Duty Schedule

September	Duty	October	Duty	November	Duty	December	Duty
Tuesday, September 1, 2020	E2	Thursday, October 1, 2020	E4	Sunday, November 1, 2020	E9	Tuesday, December 1, 2020	E2
Wednesday, September 2, 2020	E10	Friday, October 2, 2020	E12	Monday, November 2, 2020	E1	Wednesday, December 2, 2020	E10
Thursday, September 3, 2020	E3	Saturday, October 3, 2020	E11	Tuesday, November 3, 2020	E8	Thursday, December 3, 2020	E3
Friday, September 4, 2020	E6	Sunday, October 4, 2020	E5	Wednesday, November 4, 2020	E13	Friday, December 4, 2020	E6
Saturday, September 5, 2020	E4	Monday, October 5, 2020	E7	Thursday, November 5, 2020	E2	Saturday, December 5, 2020	E4
Sunday, September 6, 2020	E12	Tuesday, October 6, 2020	E9	Friday, November 6, 2020	E10	Sunday, December 6, 2020	E12
Monday, September 7, 2020	E11	Wednesday, October 7, 2020	E1	Saturday, November 7, 2020	E3	Monday, December 7, 2020	E11
Tuesday, September 8, 2020	E5	Thursday, October 8, 2020	E8	Sunday, November 8, 2020	E6	Tuesday, December 8, 2020	E5
Wednesday, September 9, 2020	E7	Friday, October 9, 2020	E13	Monday, November 9, 2020	E4	Wednesday, December 9, 2020	E7
Thursday, September 10, 2020	E9	Saturday, October 10, 2020	E2	Tuesday, November 10, 2020	E12	Thursday, December 10, 2020	E9
Friday, September 11, 2020	E1	Sunday, October 11, 2020	E10	Wednesday, November 11, 2020	E11	Friday, December 11, 2020	E1
Saturday, September 12, 2020	E8	Monday, October 12, 2020	E3	Thursday, November 12, 2020	E5	Saturday, December 12, 2020	E8
Sunday, September 13, 2020	E13	Tuesday, October 13, 2020	E6	Friday, November 13, 2020	E7	Sunday, December 13, 2020	E13
Monday, September 14, 2020	E2	Wednesday, October 14, 2020	E4	Saturday, November 14, 2020	E9	Monday, December 14, 2020	E2
Tuesday, September 15, 2020	E10	Thursday, October 15, 2020	E12	Sunday, November 15, 2020	E1	Tuesday, December 15, 2020	E10
Wednesday, September 16, 2020	E3	Friday, October 16, 2020	E11	Monday, November 16, 2020	E8	Wednesday, December 16, 2020	E3
Thursday, September 17, 2020	E6	Saturday, October 17, 2020	E5	Tuesday, November 17, 2020	E13	Thursday, December 17, 2020	E6
Friday, September 18, 2020	E4	Sunday, October 18, 2020	E7	Wednesday, November 18, 2020	E2	Friday, December 18, 2020	E4
Saturday, September 19, 2020	E12	Monday, October 19, 2020	E9	Thursday, November 19, 2020	E10	Saturday, December 19, 2020	E12
Sunday, September 20, 2020	E11	Tuesday, October 20, 2020	E1	Friday, November 20, 2020	E3	Sunday, December 20, 2020	E11
Monday, September 21, 2020	E5	Wednesday, October 21, 2020	E8	Saturday, November 21, 2020	E6	Monday, December 21, 2020	E5
Tuesday, September 22, 2020	E7	Thursday, October 22, 2020	E13	Sunday, November 22, 2020	E4	Tuesday, December 22, 2020	E7
Wednesday, September 23, 2020	E9	Friday, October 23, 2020	E2	Monday, November 23, 2020	E12	Wednesday, December 23, 2020	E9
Thursday, September 24, 2020	E1	Saturday, October 24, 2020	E10	Tuesday, November 24, 2020	E11	Thursday, December 24, 2020	E1
Friday, September 25, 2020	E8	Sunday, October 25, 2020	E3	Wednesday, November 25, 2020	E5	Friday, December 25, 2020	E8
Saturday, September 26, 2020	E13	Monday, October 26, 2020	E6	Thursday, November 26, 2020	E7	Saturday, December 26, 2020	E13
Sunday, September 27, 2020	E2	Tuesday, October 27, 2020	E4	Friday, November 27, 2020	E9	Sunday, December 27, 2020	E2
Monday, September 28, 2020	E10	Wednesday, October 28, 2020	E12	Saturday, November 28, 2020	E1	Monday, December 28, 2020	E10
Tuesday, September 29, 2020	E3	Thursday, October 29, 2020	E11	Sunday, November 29, 2020	E8	Tuesday, December 29, 2020	E3
Wednesday, September 30, 2020	E6	Friday, October 30, 2020	E5	Monday, November 30, 2020	E13	Wednesday, December 30, 2020	E6
		Saturday, October 31, 2020	E7			Thursday, December 31, 2020	E4