Shift Scheduling in Healthcare: Considering Legal Regulations and Workload Fairness for Radiology Technicians

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ABSTRACT

Purpose: This study presents a mixed integer scheduling model for radiology technicians that focuses on legal regulations and employee preferences. Radiology technicians are underrepresented in literature despite being subject to strict legal and health constraints. Key features of this study include balancing total working hours and night shift assignments, considering voluntary overtime preferences, radiation safety regulations, and gender-sensitive technician requirements.

Methodology: The MIP model was developed for multi-week scheduling to balance workload among technicians who volunteer for overtime. The model has been validated in a public hospital in Türkiye.

Findings*:* The proposed model has resulted in measurable and radical improvements in workforce management. The standard deviation in total working hours decreased from 53.92 to 2.95, showing an improvement of approximately 95%. Similarly, the standard deviation in night shift distribution decreased from 2.19 to 0.61. The model achieved 100% compliance with legal regulations and personnel preferences by generating an optimal solution in a short time of 1.34 seconds.

Originality: This study presents an original model that combines radiation safety constraints with an equity framework based on individual preferences. It makes a contribution to literature, particularly by maximizing operational efficiency in seconds while protecting the legal rights of technicians and by considering gender-sensitive technician requirements.

Keywords**:** Shift Scheduling, Healthcare Operations, Healthcare Staff Rostering, Radiology Technician Scheduling, Fair Shift Scheduling, Equity in Shift Scheduling, Sustainable Workforce Management, Health Policy, Health Systems.

JEL Codes: C61, C44, M11.

Sağlık Sektöründe Vardiya Çizelgelemesi: Radyoloji Teknisyenleri Açısından Yasal Düzenlemeler ve İş Yükünde Adaletin Gözetilmesi

ÖZET

Amaç: Bu çalışma, yasal düzenlemelere ve çalışan tercihlerine odaklanan, radyoloji teknisyenleri için karma tamsayı çizelgeleme modeli sunmaktadır. Radyoloji teknisyenleri, katı yasal ve sağlık kısıtlamalarına tabi olmalarına rağmen literatürde yeterince temsil edilmemektedir. Bu çalışmanın temel özellikleri arasında toplam çalışma saatleri ve gece vardiyası görevlendirmelerinin dengelenmesi, gönüllü fazla mesai tercihlerinin, radyasyon güvenliği düzenlemelerinin ve cinsiyete duyarlı teknisyen gereksinimlerinin dikkate alınması yer almaktadır.

Yöntem: Model, fazla mesaiye gönüllü olan teknisyenler arasında iş yükünü dengelemek amacıyla çok haftalık çizelgeleme için geliştirilmiştir. Model, Türkiye'deki bir kamu hastanesinde doğrulanmıştır.

Bulgular: Önerilen model, iş gücü yönetiminde ölçülebilir ve köklü iyileştirmeler sağlamıştır. Toplam çalışma saatlerindeki standart sapma 53,92'den 2,95'e düşerek yaklaşık %95'lik bir iyileşme göstermiştir. Benzer şekilde, gece vardiyası dağılımındaki standart sapma 2,19'dan 0,61'e düşmüştür. Model, 1,34 saniyelik kısa bir sürede optimal bir çözüm üreterek yasal düzenlemelere ve personel tercihlerine %100 uyum sağlamıştır.

Özgünlük: Bu çalışma, radyasyon güvenliği kısıtlamalarını bireysel tercihlere dayalı bir eşitlik çerçevesiyle birleştiren özgün bir model sunmaktadır. Özellikle teknisyenlerin yasal haklarını korurken ve cinsiyete duyarlı teknisyen gereksinimlerini dikkate alırken operasyonel verimliliği saniyeler içinde en üst düzeye çıkararak literatüre katkı sağlamaktadır.

Anahtar Kelimeler: Vardiya Planlaması, Sağlık Hizmetleri Operasyonları, Sağlık Personeli Çizelgelemesi, Radyoloji Teknisyeni Çizelgelemesi, Adil Vardiya Planlaması, Vardiya Planlamasında Eşitlik, Sürdürülebilir İş Gücü Yönetimi, Sağlık Politikası, Sağlık Sistemleri.

JEL Kodları: C61, C44, M11.

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1. INTRODUCTION

Shift scheduling is a critical workforce management problem frequently encountered in healthcare, transportation, security, manufacturing, and service sectors. It requires assigning staff to shifts within a defined planning horizon while considering operational requirements, legal regulations, and employee well-being and preferences. Effective scheduling must consider working hours, rest periods, consecutive shift restrictions, employee preferences, and institutional policies. Beyond operational efficiency, fairness and workload balance have become fundamental considerations, especially in healthcare institutions (Hamid et al., 2019; Karayel and Atmaca, 2017). Recent research highlights the importance of workload balancing and fairness in practical healthcare contexts (Alaouchiche et al., 2024; Wolbeck, 2019). Flexible modeling of workload criteria increases both efficiency and fairness. In addition, integrating equity-focused constraints into scheduling systems strengthens staff satisfaction and organizational sustainability (Gerlach et al., 2025).

In healthcare settings, poorly designed schedules may cause staff dissatisfaction that directly impacts patient safety and quality of service. Manual scheduling has been shown to consume significant administrative time while also creating inefficiencies and inequities in workload distribution (Al-Mudahka and Alhamad, 2022; Baum et al., 2014; O'Connell et al., 2024). Recent advances in scheduling approaches emphasize the role of mathematical models and AI-based systems in improving fairness, transparency, and staff satisfaction (Gerlach et al., 2025; O'Callahan et al., 2024). However, radiology departments pose additional challenges due to the continuous demand for diagnostic services, the need for specialized expertise, and strict legal regulations governing radiation exposure. Radiology staff face long-term health risks from ionizing radiation, requiring compliance with regulations such as maximum working hours, mandatory rest periods, and rotating between day and night shifts (Özcan et al., 2019; Yuura et al., 2017; IAEA, 2018; UK Government, 2017). At the same time, staff shortages frequently require overtime work, which may lead to inequalities in workload and income distribution (Baum et al., 2014; O'Callahan et al., 2024).

Recent studies also emphasize that prolonged overtime is a strong predictor of increasing burnout among healthcare workers, highlighting the need for scheduling systems that limit involuntary overtime and promote equitable workload distribution to protect staff well-being and quality of care (Chen et al., 2025). This tension underscores the need for models that ensure service continuity, protect employee health, and promote equity in both workload and earnings.

While shift scheduling has been widely studied in healthcare, most research has focused on nurses (Hamid et al., 2019; Karayel and Atmaca, 2017; El Adoly et al., 2018; Lim et al., 2012; Yilmaz, 2012; Burke and Curtois, 2014) and doctors (Chawasemerwa et al., 2018; Puente et al., 2009; Tucker et al., 2010), with relatively limited attention paid to radiology technicians despite their distinct regulatory, operational, and safety constraints. Reflecting the recent progress in physician scheduling, Cappanera et al. (2022) proposed an integer scheduling approach targeting equitable workload for emergency department physicians. This approach is methodologically consistent with the equity-based model we developed for radiology technicians in our study. Both studies are based on an equitable workload distribution for critical healthcare personnel. Also, Özcan et al. (2019) proposed a goal programming model for a small group of technicians in a hospital, primarily aimed at minimizing deviations in total working hours. Other models have incorporated radiographers' skills and training requirements into the scheduling process (Yuura et al., 2017). More recent AI-based systems have been able to accommodate shift preferences while ensuring service continuity (O'Callahan et al., 2024). Additionally, approaches from an income management perspective have focused on increasing the income of lower-earning staff (Baum et al., 2014). Table 1 has been prepared to provide a general overview of the existing literature and to demonstrate the contribution of this study to the literature. The studies in Table 1 are compared in terms of staff group, method used, fairness approach, and the key constraints considered in the model. It also summarizes whether night shift equity and income/overtime aspects were addressed, and the regulatory or context-specific constraints considered in each study.

While prior studies have advanced healthcare scheduling research, two important gaps remain in the literature: (i) radiology technicians are underrepresented in shift scheduling research although regulatory and healthcare constraints are required; and (ii) existing models often overlook workload fairness and voluntary overtime preferences, both of which are fundamental to sustainable shift scheduling in healthcare institutions. To address these gaps, we develop a mixed integer programming (MIP) model for scheduling radiology technicians. While most existing healthcare scheduling models focus on nurses or physicians and primarily emphasize coverage requirements, skill mix, and general workload balance, radiology-technician scheduling involves additional regulatory and safety dimensions, particularly radiation exposure limits and strict shift rotation policies. The proposed model incorporates institutional policies and workload fairness criteria, as well as legal requirements such as radiation exposure restrictions, rest periods, and consecutive

shifts. Specifically, it balances total working hours, distributes night shifts equitably, accommodates voluntary overtime preferences, and ensures compliance with gender-sensitive staffing requirements (e.g., the presence of female technicians for mammography procedures). By explicitly integrating workload fairness, regulatory compliance, and context-specific operational constraints within a unified optimization framework, the proposed model contributes a more comprehensive and radiology-specific approach to healthcare workforce scheduling.

Overall, existing healthcare scheduling models have primarily focused on nurse and physician contexts, typically emphasizing coverage requirements, skill mix, and general workload balance. Compared to these models, radiology-technician scheduling involves additional layers of regulatory and safety constraints, particularly radiation exposure limits and strict shift rotation policies. While prior studies have addressed fairness or overtime considerations in isolation, few models integrate workload fairness, voluntary overtime preferences, radiation safety regulations, and gender-sensitive staffing requirements within a unified optimization framework. By explicitly combining these dimensions in a mixed-integer programming model tailored to radiology departments, this study extends existing healthcare scheduling approaches and offers a more context-specific and sustainability-oriented perspective.

The remainder of this paper is organized as follows. Section 2 describes the problem in detail. Section 3 presents the proposed solution methodology, while Section 4 presents computational results from the case study. Finally, Section 5 concludes the paper and offers directions for future research.

Table 1. Comparison of fairness-oriented healthcare staff scheduling studies

Study	*Staff Type*	*Method*	*Fairness Dimension*	*Fairness Operationalization*	*Night Shift Equity*	*Income / Overtime*	*Regulatory / Context-Specific Constraints*
Hamid et al. (2019)	Nurses	Multi-objective MIP	Workload balance	Objective function terms	Implicit	✗	Rest rules
Alaouchiche et al. (2024)	Nurses	Optimization	Workload balancing	Variance minimization	✓	✗	Staffing requirements
Baum et al. (2014)	Radiology staff	Optimization	Income fairness	Revenue-based metrics	✓	✓	Departmental policies
Cappanera et al. (2022)	Healthcare staff	Mathematical programming	Equity metrics	Explicit equity indicators	✓	✗	Organizational rules
O'Callahan et al. (2024)	Radiology	AI-based	Preference satisfaction	Preference-weighted allocation	✗	✓	Self-rostering framework
Özcan et al. (2019)	Radiology technicians	Goal programming	Working hour deviation	Goal deviation minimization	✗	✗	Ray permission
Yuura et al. (2017)	Radiographers	IP	Skill balance	Skill-based constraints	✗	✗	Training & Safety
This study	Radiology technicians	MIP	Workload and night shift fairness	Explicit minimization of Δt and Δn	✓	✓	Radiation, gender-sensitive care

2. PROBLEM DEFINITION

In this study, we address shift scheduling for radiology technicians working under limited resources and strict health and policy requirements. The goal is to create feasible schedules that comply with legal regulations, ensure continuity of healthcare services, and promote fairness among employees. The planning horizon consists of a fixed period of consecutive days, divided into daily shifts. Each day has two shifts: a day shift and a night shift, collectively denoted by the set J. The subset JD represents weekday day shifts, while JN refers to night shifts. Weekly planning is incorporated through the set K, where J_k⊆ J denotes the subset of shifts corresponding to week $k \in K$.

The set of technicians is represented by I, that indicates all technicians to be scheduled. To reflect institutional and legal requirements, this set is partitioned into subsets according to technician characteristics. Specifically, the subset IF indicates female technicians (to ensure gender-sensitive technician scheduling by requiring the presence of female technicians, in alignment with patient preferences), the subset IH denotes technicians who prefer not to work overtime and are assigned only minimum working hours, the subset $I0$ refers to technicians who voluntarily accept overtime and get overtime payment, and IL includes technicians on ray permission during the planning period. These subsets enable the incorporation of heterogeneous employee preferences and rights into the scheduling process. It should be noted that these subsets are not mutually exclusive; a technician may belong to more than one

subset simultaneously (e.g., a female technician who voluntarily accepts overtime). Moreover, α represents the maximum allowable number of day shifts per technician and β specifies the maximum allowable number of night shifts per technician within the planning horizon. Each shift $j \in J$ has an associated duration parameter WH_j, that defines the working hours of a technician assigned to that shift. To ensure continuity of service, a minimum number of people must be assigned to each shift, represented by the parameter R_j. Legal restrictions on working hours are incorporated using two parameters: WT, which specifies the maximum permissible weekly working hours, and MW, which specifies the minimum weekly working hours required. These limits ensure compliance with public health regulations while supporting workload fairness and employee well-being.

To promote equity among employees, the workload-balancing mechanism is applied only to technicians who volunteer for overtime. Technicians who do not wish to work overtime are fixed at their minimum contractual working hours and are therefore exempt from additional workload adjustments. However, workload imbalances may arise among technicians who opt for overtime. For this reason, fairness constraints are enforced exclusively within this voluntary group. Technicians who do not work overtime remain included in the model to ensure overall feasibility of the schedule, but workload equity is evaluated and maintained only among those who are eligible and willing to undertake overtime assignments.

3. PROPOSED MATHEMATICAL MODEL

For the problem defined, we formulate a mixed integer programming (MIP) model to generate schedules for radiology technicians working under limited resources and strict health and policy requirements. The primary decision variable of the model, X_{ij}, is a binary variable indicating whether technician i is assigned to shift j. Additionally, several continuous variables are introduced to capture workload distribution, night shift allocation, and fairness criteria. Specifically, t_{max} denotes the total working hours of the technician working overtime with the highest workload, while t_{min} represents the total working hours of the technician working overtime with the lowest workload. The difference between these two values, Δt, measures inequality in total working hours across the workforce of the technicians working overtime. Night shift assignments are modeled similarly: n_i represents the total number of night shifts assigned to technician i, and n_{max} and n_{min} represent the highest and lowest number of night shifts assigned to the technicians working overtime, respectively. The difference between these values, Δn, reflects the unbalanced distribution of night shifts among technicians working overtime. The objective of the proposed model is to minimize the difference in total working hours and in night shift assignments among technicians working overtime. η_1 is weight of the first objective (difference in total working hours) whereas η_2 is the weight of the second objective (difference in night shift assignments).

All sets, parameters, and decision variables utilized across the proposed mathematical model are defined below.

Sets:

I	Set of technicians
IH	Set of weekly 35 hours working technicians i.e., $IH \subseteq I$
IO	Set of technicians working overtime i.e., $IO \subseteq I$
IL	Set of technicians on radiation permission during the planning period, i.e., $IL \subseteq I$
IF	Set of female technicians not on radiation permission i.e., $IF \subseteq I$
JD	Set of weekday day shifts
JN	Set of night shift
J	Set of shifts i.e., J = $JD \cup JN$ and J={1,2,…,$\|J\|$}
K	Set of weeks
J_k	Set of shifts corresponding to week, $k \in K, J_k \subseteq J$

Parameters:

WT	Maximum weekly working hours of a technician
MW	Minimum weekly working hours
$\|I\|$	Total number of technicians.
R_j	Minimum number of technicians required to work in shift j.

WH_j Working hours in shift j.

α Maximum allowable number of day shifts per technician within the planning horizon

β Maximum allowable number of night shifts per technician within the planning horizon

η_1 Weight of the first objective (difference in total working hours)

η_2 Weight of the second objective (difference in night shift assignments)

Decision variables:

$X_{ij} = \begin{cases} 1, & \text{if technician i assigned shift j} \\ 0, & \text{otherwise} \end{cases}$

t_{max} Total working hours of the most assigned technician working overtime.

t_{min} Total working hours of the least assigned technician working overtime.

Δt Difference in total working hours among technicians working overtime.

Δn Difference in night shift assignments among technicians working overtime.

n_i Total number of night shifts assigned to technician i.

n_{max} Highest number of night shifts assigned to any technician working overtime.

n_{min} Lowest number of night shifts assigned to any technician working overtime.

$$Min\ Z\ =\ \eta_1 \Delta t\ + \eta_2 \Delta n \quad (1)$$

subject to

$$\sum_{j\ \in\ J_k} WH_j\ X_{ij}\ \leq\ \mathrm{WT} \qquad \forall i \in IO, \forall k \in K \quad (2)$$

$$\sum_{i \in (\mathrm{IO}\ \cup\ \mathrm{IH})} X_{ij} = R_j \qquad \forall j \in J \quad (3)$$

$$X_{ij}\ +\ X_{i,j+1} \leq 1 \qquad \forall i \in (\mathrm{IO}\ \cup\ \mathrm{IH}), \forall j \in J \text{ and } J < |J|\text{-}1, \quad (4)$$

$$X_{ij}\ +\ X_{i,j+1} + X_{i,j+2} \leq 1 \qquad \forall i \in (\mathrm{IO}\ \cup\ \mathrm{IH}), \forall j \in JN \text{ and } J < |J|\text{-}2, \quad (5)$$

$$\sum_{j\ \in\ J} X_{ij} = 0 \qquad \forall i \in IL \quad (6)$$

$$\sum_{j\ \in\ J_k} WH_j X_{ij}\ =\ \mathrm{MW} \qquad \forall i \in IH, \forall k \in K \quad (7)$$

$$\sum_{i\ \in\ IF} X_{ij} \geq 1 \qquad \forall j \in JD \quad (8)$$

$$t_i = \sum_j WH_j X_{ij} \qquad \forall I \in (\mathrm{IO}\ \cup\ \mathrm{IH}) \quad (9)$$

$$t_{max} \geq t_i \qquad \forall I \in \mathrm{IO} \quad (10)$$

$$t_{min} \leq t_i \qquad \forall I \in \mathrm{IO} \quad (11)$$

$$\Delta t = t_{max} - t_{min} \quad (12)$$

$$\sum_{j\ \in\ JD} X_{ij} \leq \alpha \qquad \forall I \in (\mathrm{IO}\ \cup\ \mathrm{IH}) \quad (13)$$

$$\sum_{j\ \in\ JN} X_{ij} \leq \beta \qquad \forall i \in (\mathrm{IO}\ \cup\ \mathrm{IH}) \quad (14)$$

$$n_i\ =\ \sum_{j\ \in\ JN} X_{ij} \qquad \forall I \in (\mathrm{IO}\ \cup\ \mathrm{IH}) \quad (15)$$

$$n_{max}\ \geq\ n_i \qquad \forall i \in \mathrm{IO} \quad (16)$$

$$n_{min}\ \leq\ n_i \qquad \forall i \in \mathrm{IO} \quad (17)$$

$$\Delta n = n_{max} - n_{min} \quad (18)$$

The objective function (Equation 1) minimizes inequalities in workload distribution by jointly minimizing inequalities in total working hours and in the allocation of night shifts across technicians. Since Δt is measured in hours, Δn is multiplied by η, number of hours in a night shift to ensure comparability in the objective function. Constraints (Equation 2) enforce the legal upper limit by ensuring that the weekly working hours of technicians who accept to work overtime do not exceed the maximum working hours. Constraints (Equation 3) enforces an exact staffing requirement for each shift. Constraints (Equation 4) prevent consecutive shift assignments, preventing a technician from being assigned to both day and night shifts on

the same day or to the day shift immediately following a night shift. Constraints (Equation 5) support this structure, restricting a technician from being assigned consecutively to both the day shift of the next day and the night shift after a night shift. These restrictions aim to ensure compliance with the Ministry of Health's regulations on radiation exposure and rest periods and employee rights. Constraints (Equation 6) ensure that technicians on radiation permission during the planning period are not assigned to any shift during this period, thus respecting legal ray permission rights. Constraints (Equation 7) ensure that technicians who do not wish to work overtime are assigned exactly the minimum required working hours. Constraints (Equation 8) require that at least one female technician be assigned to each day shift in line with the patient's preference for mammography device use. In this way, patient preferences are also taken into consideration. Constraint (Equation 9) define the total number of hours each technician works during the planning period; constraints (Equation 10) and (Equation 11) determine the total hours of the technicians who work the most and the least, respectively, and thus form the upper and lower limits of the system. Constraint (Equation 12), which calculates the difference between these two values, contributes to fair task distribution by measuring the working time inequality. Constraints (Equation 13) and (Equation 14) reduce the risk of over-assignment by limiting the maximum number of day and night shifts that technicians can take in a month. Constraints (Equation 15) calculate the total number of night shifts for each technician; constraints (Equation 16) and (Equation 17) define the highest and lowest number of night shifts assigned to any technician respectively. Finally, constraint (Equation 18) supports the goal of minimizing night shift inequality by determining the difference between these two extremes. The model developed in this context offers a holistic scheduling approach that considers operational efficiency, legal compliance, patient preference and fairness among employees.

4. CASE STUDY and COMPUTATIONAL EXPERIMENT

For the problem defined, we examine a real-world case from the radiology department of a public hospital in Turkey. The planning horizon covers four weeks (28 days), represented by the set K={1,2,3,4}. Each day consists of two types of shifts: a 7-hour day shift and a 24-hour night shift, resulting in a total of 56 shifts during the planning period. All shifts are represented by the set J, and the subset $J_k \subseteq$ J denotes the corresponding shifts in week $k \in K$. For instance, J1 contains the first 14 shifts (7 days × 2 shifts).

The radiology department employs 27 radiology technicians, represented by the set I. Among them, six are female, represented by the subset $IF \subset I$. In accordance with hospital policy, at least one female technician must be assigned to the mammography unit during each day shift to address patient preferences for gender-sensitive care. Additionally, every month at least two technicians are granted legal permission for radiation protection, denoted by the subset $IL \subset I$. These technicians are excluded from all assignments during the planning period in which their permission occurs.

Working hours are scheduled on a weekly basis in accordance with the Ministry of Health's regulations. Three technicians have preferred not to work overtime and are therefore assigned exactly 35 hours per week. By contrast, technicians who volunteer overtime are allowed to work up to 49 hours per week. Technicians who work overtime receive additional payment. For that reason, it is therefore important to distribute night shift assignments fairly among these technicians. The minimum staffing requirements also vary by shift: 10 technicians are required for day shifts and 4 for night shifts. Due to operational and regulatory restrictions, a technician cannot be assigned to both day and night shifts on the same day, or to the day shift immediately after a night shift.

The objective of the model is to minimize the difference in total working hours and in night shift assignments among technicians working overtime. Since these two objectives are expressed in different units, a normalization step is required to ensure comparability within the objective function. To achieve this, in our case study we convert the second component into hours by defining η_2 as the duration (in hours) of a night shift. We set η_1=1, thereby assigning equal importance to both components in the objective function. This assignment of the weights ensures unit consistency and allows a balanced evaluation of workload equity across both dimensions.

In addition to case data, the hospital shared a 1-month shift schedule, which was accepted as a manually generated shift schedule created by the hospital. This allowed for a comparison of the results of the manual and the proposed model, enabling the measurement of model performance. The mathematical model was developed using the GAMS 25.1.3 interface and solved using CPLEX solver version 12.8.0.0. The solution time was measured as 1.34 seconds (CPLEX time), and the optimal solution was reached within this time. For clarity in subsequent analyses, the manually generated shift schedule will be referred to as the current schedule, and the shift schedule generated by the proposed mathematical model will be referred to as the proposed schedule.

Figure 1 compares the total working hours of 22 technicians who opt to work overtime over a four-week planning horizon for both current and proposed schedules. The first three technicians are not included since

they are the technicians who do not prefer overtime. The current program exhibits significant fluctuations, with considerable differences in the total working hours assigned to different technicians. In contrast, the proposed program provides a much more uniform distribution, significantly reducing workload variations among technicians. This demonstrates that the goal of balancing total working hours, central to the model's design, has been successfully achieved. It's also noteworthy that the first three technicians in the proposed schedule have lower total hours than the others. This is because they chose not to work overtime, but the results confirm that they still meet the contract's minimum requirement of 140 hours.

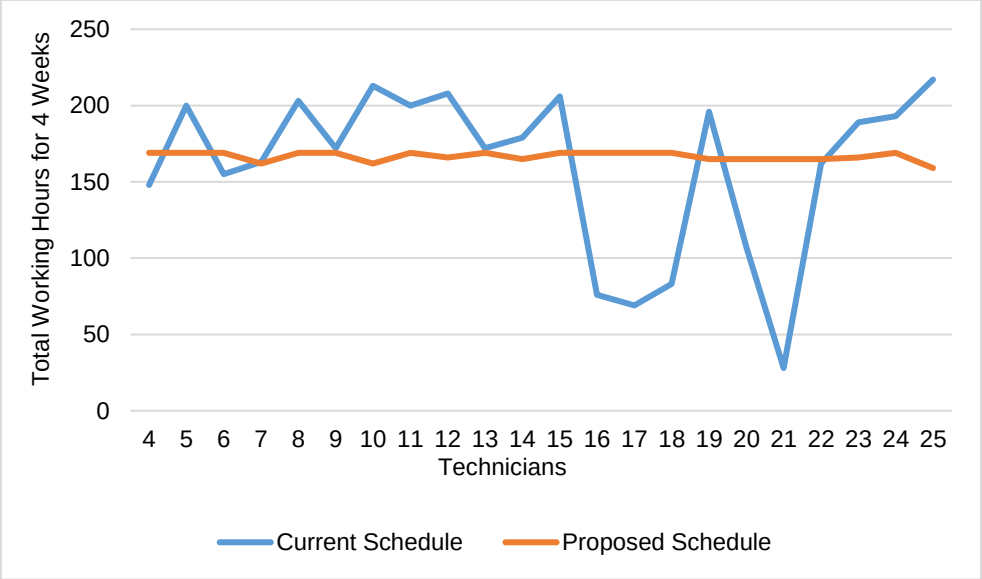


Figure 1. Comparison of total working hours across technicians: Current vs. proposed schedule

Figure 2 shows the distribution of night shift assignments among 22 technicians who prefer to work overtime. Similar to the total working hours, the current schedule exhibits significant imbalances. For example, technicians 10 and 15 are assigned eight-night shifts each, while technician 21 is assigned no night shifts at all. Such inconsistencies undermine the fairness of workload distribution. In contrast, the proposed schedule distributes night shifts more evenly, with the exception of the first three technicians, who are exempt from overtime. This ensures equity without violating individual preferences.

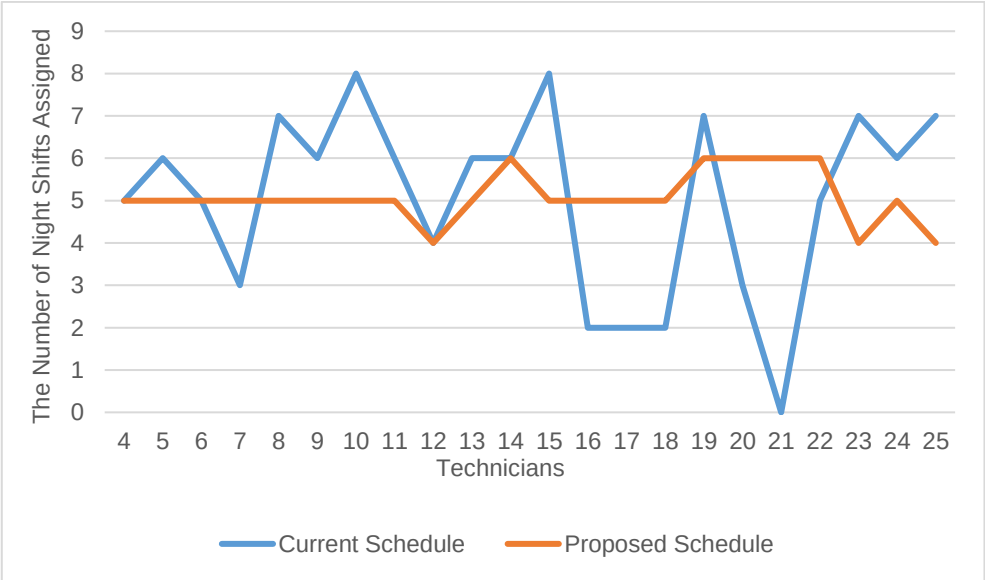


Figure 2. Comparison of night shift assignments across technicians: Current vs. proposed schedule

To complement the graphical results shared in Figure 1 and 2, Table 2 presents the exact values of total working hours and night shift assignments across technicians for both the current and proposed schedules, providing a concise numerical overview of the comparison.

Table 2. Numerical summary of total working hours and night shift assignments for current and proposed schedules

	Total Working Hours		*The Number of Assigned Night Shifts*	
Technicians	*Current Schedule*	*Proposed Schedule*	*Current Schedule*	*Proposed Schedule*
1	126	140	0	0
2	126	140	0	0
3	122	140	1	0
4	148	169	5	5
5	200	169	6	5
6	155	169	5	5
7	163	162	3	5
8	203	169	7	5
9	172	169	6	5
10	213	162	8	5
11	200	169	6	5
12	208	166	4	4
13	172	169	6	5
14	179	165	6	6
15	206	169	8	5
16	76	169	2	5
17	69	169	2	5
18	83	169	2	5
19	196	165	7	6
20	107	165	3	6
21	28	165	0	6
22	162	165	5	6
23	189	166	7	4
24	193	169	6	5
25	217	159	7	4

Table 3 shows how many female technicians numbered 3, 5, 6, 8, 11, and 13 worked the specified weekday day shifts by comparing the results of current and proposed schedules. For example, in the proposed model, 2 female technicians were assigned to the day shift on the first day. In the current schedule, no woman was assigned to the day shift on the first day. The proposed model effectively implemented the constraint by ensuring that at least 1 female technician was assigned to all weekday day shifts.

Table 3. Comparison of daily female technician assignments

	Number of Female Technicians Working That Day	
Weekday Working Days	*Proposed Schedule*	*Current Schedule*
1	2	0
2	1	1
3	2	0
4	3	0
5	3	1
8	3	4
9	3	3
10	2	0
11	2	0
12	2	2
15	4	1
16	3	4
17	3	0
18	4	0
19	5	3
22	3	4
23	2	1
24	2	2
25	3	2
26	3	3

Table 4 represents a section of the results table transferred from the Gams application to Excel. Table 3 shows whether technicians 17-23 were assigned to the day and night shifts on days 22, 23, and 24. Cells

filled with 1 indicate that an assignment was made to the specified shift on that day. For example, technician 21 was assigned to the night shift on day 22, technician was not assigned to the day or night shift on day 23. Additionally, it is observed that a technician assigned to a day or night shift on any given day is not assigned to another shift on that day.

Table 4. Partial view of shift assignments (Days 22–24)

	Day 22		*Day 23*		*Day24*	
Technicians	*Day Shift*	*Night Shift*	*Day Shift*	*Night Shift*	*Day Shift*	*Night Shift*
17					1	
18	1		1		1	
19				1		
20	1		1		1	
21		1				
22				1		
23	1		1			

Table 5 summarizes the mathematical performance by comparing the standard deviation values of the current system and the proposed model for 22 technicians who opt to work overtime. The standard deviation in total working hours decreased from 53.92 to 2.95, significantly eliminating workload imbalance among technicians. Similarly, the deviation in night shift distribution decreased from 2.19 to 0.61, proving that shifts are distributed much more evenly among employees. These sharp decreases in standard deviation confirm that the proposed scheduling creates a more equitable structure that preserves employee preferences compared to the current scheduling.

Table 5. Comparison of standard deviations between current and proposed schedules

Standard Deviation	*Current Schedule*	*Proposed Schedule*
Total Working Hours	53.92	2.95
The Number of Assigned Night Shifts	2.19	0.61

Figure 3 illustrates the deviations of individual technicians' total working hours from the average. The current work schedule exhibits large deviations, with some technicians working close to the average (e.g., Technicians 6 and 7) while others work significantly above or below the average (e.g., Technicians 21 and 25). This suggests a high inequality in workload distribution, consistent with a large variance and standard deviation. However, the proposed work schedule exhibits much smaller deviations with low fluctuations across all technicians. This demonstrates that the mathematical model successfully mitigates workload inequalities and provides a more equitable distribution of working hours.

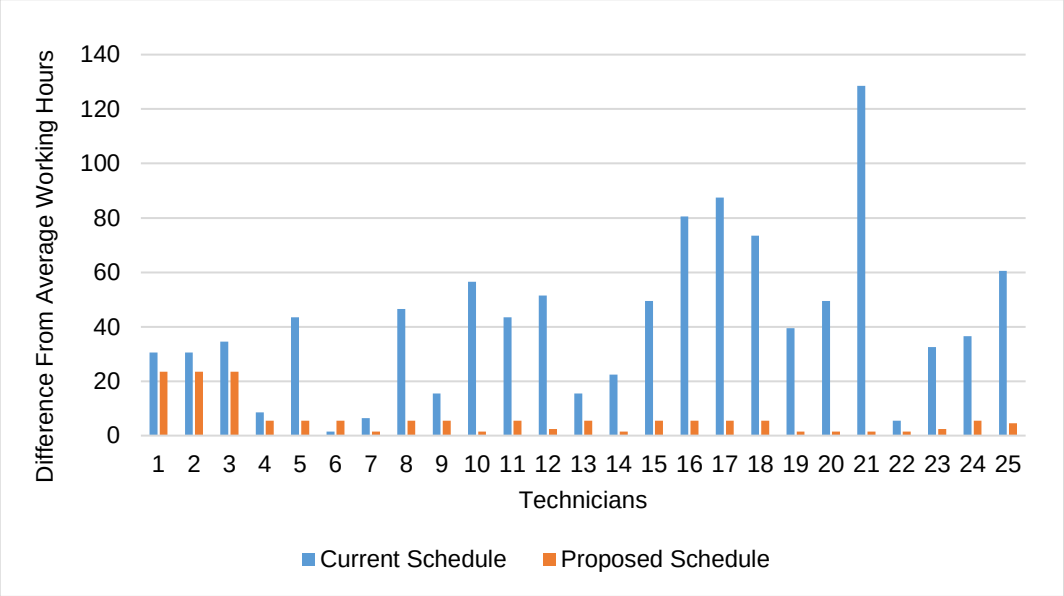


Figure 3. Deviation from average working hours per technician: Current vs. proposed schedule

Overall, the comparative results highlight that the proposed model enhances fairness in both total working hours and night shift assignments while respecting individual preferences and organizational constraints.

5. CONCLUSION

This study focuses on the shift scheduling problem of radiology technicians in healthcare institutions. A mixed integer programming (MIP) model has been developed that addresses legal regulations, employee welfare, and service continuity. The proposed model encompasses legal constraints such as radiation exposure, rest periods, and consecutive shifts, along with institutional policies such as voluntary overtime, gender-sensitive technician assignment for mammography machines, and working hour limits. The main objective is to increase workload fairness among personnel by reducing inequalities in total working hours and night shift distribution.

The developed model was tested and validated in a public hospital in Türkiye. Comparative results showed that the proposed model provided a much more balanced workload and shift distribution compared to manual scheduling. The model minimized workload fluctuations and strengthened equity among personnel while complying with all legal and institutional requirements. These findings reveal the potential of mathematical optimization to increase workforce sustainability and equity in healthcare institutions.

There are various future directions for this study. First, the model could incorporate multiple skill technicians to assign them to areas where they expertise. Second, stochastic modeling approaches for demand uncertainty could be integrated. Third, expanded fairness objectives such as long-term income stability and career opportunities could be included. Moreover, future research could include comprehensive sensitivity and scenario analyses by changing parameters such as weekly hour limits, night shift quotas, and equity weights to further examine the robustness of the proposed framework. Testing the model on larger problem samples, including multiple departments or hospitals, will also provide insight into its scalability and computational performance.

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Author Contributions
Eylül Şener: Methodology, Data Curation, Analysis, Writing-original draft *Bengisu Şenbaş*: Literature Review, Methodology, Analysis, Writing-original draft *Betül Kayışoğlu*: Conceptualization, Analysis, Writing-review and editing

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It was declared by the authors that the tools and methods used in the study do not require the permission of the Ethics Committee.

Ethical Statement
It was declared by the authors that scientific and ethical principles have been followed in this study and all the sources used have been properly cited.



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