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Research Article

A Constraint Programming Model for Personnel Scheduling Problem: Application in A Factory Operating in Healthcare Sector

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Abstract
Disruptions in the healthcare sector are a significant concern for companies as they directly affect human health. One of the key factors to ensure smooth operations and prevent disruptions is the personnel. In order to prevent personnel from making mistakes, the imbalances and injustices in the system should be addressed. This study addresses the problem of assigning shifts as evenly as possible to personnel working in the production department of a factory operating in the healthcare sector in Ankara. Constraint programming was employed to meet the goals and fulfill the company and personnel requirements with minimal deviation. A constraint programming model was established under specific constraints for a factory operating with two shifts and 30 personnel, and it was solved using the ILOG Cplex program. The proposed constraint programming model achieved the goal values with lower than expected values. The 31-day schedule obtained resulted in a more balanced workload distribution, leading to increased personnel satisfaction. This study is the first in the literature to address the personnel scheduling problem in the healthcare sector using the constraint programming method.

Keywords
Personnel scheduling, constraint programming, shift scheduling

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1. Introduction

Scheduling can be defined as the assignment of scarce resources such as machinery, equipment, and labor to tasks in a manner that serves a specific purpose within certain constraints, provided that the start and end times are specified. The aim of the scheduling process is to allocate these scarce resources to appropriate tasks in a way that optimizes the organization's objectives. An effective scheduling process ensures that certain activities can be completed in a shorter time with fewer resources (Güldalı, 1990).

The primary objective in the healthcare sector is to protect the physical and mental health of the community and to provide services that are prompt, effective, reliable, tested, of high quality, and low cost when needed. Disruptions in the healthcare sector are of critical importance in this context. These disruptions may occur due to errors resulting from a lack of morale among staff (Ekiyor & Arslantaş, 2015). Lack of morale and inattentiveness can arise in conditions where staff are unable to work under fair conditions, find the tasks overwhelming, or have insufficient vacation days. The personnel scheduling problem, a sub-problem of scheduling issues, is of significant importance for businesses (Koçak et al., 2023). Institutions should create schedules by considering workers' preferences and satisfaction, the qualifications required by the task, working hours, and other relevant factors (Cürebal et al., 2020). By doing so, they contribute to the efficient progress of business operations (Özcan et al., 2017).

The literature frequently observes that personnel scheduling problems are solved using mathematical models (Eren et al., 2017). In this study, the problem was solved using the constraint programming method. Constraint programming is an optimization method where the values that variables can take are within certain limits. Variables, constraints, and the solution set form the problem's main structure. The established models do not require an objective function.

This study addressed the shift scheduling problem of production personnel in a factory operating in the healthcare sector in Ankara. In the mentioned department, 30 personnel work in two shifts. The aim was to ensure the fair assignment of personnel to the respective shifts.

The subsequent sections of the study are organized as follows. The second section discusses the personnel scheduling problem. The third section presents constraint programming as the solution method for the addressed problem. The fourth section reviews and presents personnel scheduling problems in the literature. The fifth section contains the case study. The sixth section provides the results obtained and recommendations for future research.

2. Personnel Scheduling Problem

Scheduling is the assignment of resources such as machinery, operators, and tools to tasks within a certain time frame, serving a specific purpose under certain constraints. The fundamental elements of scheduling are resources, time, and activities. Determining the sequence in which a product or service should be processed is a scheduling problem. The objectives of scheduling problems include the efficient use of resources, quick response to demand, and minimization of delays and total completion time.

There are many sub-problems with scheduling. The personnel scheduling problem, which is frequently mentioned in the literature and addressed in this study, is a problem that firms need to consider (Özcan et al., 2017). The primary cause of disruptions stems from personnel errors. Personnel experience low motivation in environments with unbalanced work distribution, unfair schedules, and harsh physical conditions. Consequently, the desired efficiency from personnel cannot be achieved (Aksüt et al., 2022).

When examining the factors that unnecessarily burden personnel and prevent them from working error-free, we can identify two main problem areas: the personnel assignment problem and the personnel scheduling problem (Atmaca et al., 2012). The personnel scheduling problem is divided into various sub-problems. Shift scheduling problems, which include the problem addressed in this study, are one of these sub-problems. Factors such as company and personnel preferences, a fair working environment, personnel competencies, working hours, ergonomic risks, and other factors are considered when assigning personnel to existing or additional shifts. The most important elements to consider here are the fair distribution of vacation days to enhance personnel satisfaction and company efficiency.

The primary objective of healthcare services is to provide the necessary healthcare services to the community at the desired quality, at the desired time, and at the lowest possible cost (Atmaca et al., 2012). Disruptions are of critical importance as they directly affect human health. In this context, companies operating in the healthcare sector must carefully address the employee scheduling problem.

3. Constraint Programming

The constraint programming method is a mathematical modeling approach that seeks to find the best solution under specific constraints. In this approach, the main logic is to formulate the problem's constraints using mathematical and logical expressions and define appropriate solution spaces (Alağaş et al., 2013).
Variables, the solution set, and notations form the main structure of constraint programming. Decision variables take discrete values. There is no requirement for an objective function, but this condition is sought in constraint optimization problems. A value in the

solution set may be assigned to a variable. Constraint programming can be applied in operations research, graphical systems, business applications, electrical circuits, algebraic computations on computers, molecular biology, and other fields.

The constraint satisfaction model is represented in the form of a triple notation (X, D, C). X is the set of variables, $X = \{X_1, \dots, X_n\}$. The domain, or solution set, D is represented as $v_i \in D_{(x_i)} i = 1, \dots, n$. The set of constraints C is denoted as $C_j = \{C_1, \dots, C_m\}$. In some models, the objective function is represented as $H = (x_1, \dots, x_n)$. A general structure of a CP model is shown below (Apt, 2003):

$$minimize\ H = (x_1, \dots, x_n)$$
$$subject\ to$$
$$C_j = \{C_1, \dots, C_m\} \quad \forall j \in \{1, \dots, m\} \tag{1}$$
$$x_i \in D_i \quad \forall j \in \{1, \dots, n\} \tag{2}$$

The CP model will yield results if the decision variables take values from the domain and satisfy the constraints.

4. Literature Review

There are numerous studies on personnel scheduling problems in the literature. This section presents some of these studies.

In their 2020 study, Cürebal et al. addressed the personnel scheduling problem for a promotional festival, initially prioritizing tasks using the AHP method and then proposing a goal programming model. The study tackled a real-life problem and provided a model proposal for a sector that has not been extensively studied in the literature. Özder et al. (2017) addressed the personnel scheduling problem using the goal programming method, assigning cleaning personnel in a university hospital, resulting in a fairer assignment compared to the existing schedule. Eren et al. (2021) examined the personnel assignment problem for a gas station and attempted to solve it using the goal programming method, considering personnel preferences and assigning them to equal shifts. Ünal and Eren (2016) used the weighted goal programming method as a solution approach, scheduling shifts in a government institution, aiming to assign shifts according to seniority levels and personnel requests. Koçtepe et al. (2018) addressed the personnel scheduling problem for event organizers, using the integer programming method in the solution phase, considering personnel competencies in the model. Demirel et al. (2018) worked on creating a work plan for ANKARAY security personnel, using the goal programming method, achieving equal shift distribution in the resulting schedule. Özcan et al. (2017) addressed the shift scheduling problem in hydroelectric power plants using the goal programming method. They achieved a 91% improvement in downtime caused by operator errors using real data in the study. In their study, Bektur and Hasgül (2013) created a schedule using the goal programming method by considering the skills, seniority levels, preferences, and demands of the personnel. In their work, Ciritcioğlu et al. (2017) focused on equitable and fair shift scheduling for three different categorized security personnel at Kırıkkale University, utilizing the goal programming method in model development. Supçiller and Erbilek (2021) employed goal programming and AHP methods to assign 42 part-time students working at a university's central library to appropriate days and shifts, taking into account their class schedules. In their study, Cürebal and Eren (2021) addressed the shift scheduling of security personnel at a hospital in Ankara. They integrated AHP-TOPSIS methods by considering six criteria to solve the problem and used goal programming in the assignment phase. Lezaun et al. (2006) examined the workforce scheduling problem of workers on a metro line in their study and proposed a solution using the integer programming method. Chu (2007) examined the scheduling problem of personnel working in baggage services at an airport. A solution was proposed using the goal programming method. Fırat and Hurkens (2012) investigated the personnel scheduling problem related to the timing of complex tasks with a heterogeneous resource set. A mixed-integer programming model was proposed to solve the problem. Kassa and Tizazu (2013) studied the workforce assignments of hotel personnel. Excel solver was used in the model solution to ensure a balanced workforce. Bedir et al. (2017) attempted to solve the shift scheduling problem under ergonomic conditions, using AHP and goal programming as methods. Bolayır (2023) focused on the shift scheduling of the emergency department of a state hospital during the pandemic, using the 0-1 integer goal programming method. Kaçmaz et al. (2020) worked on the ergonomic personnel scheduling problem in the glass industry, using REBA and goal programming methods in the solution phase. In his thesis, Keskinkılıç (2021) created a schedule considering the competencies and satisfaction of call center personnel, solving it with a mathematical model. Koçak et al. (2022) addressed the scheduling of personnel involved in contact tracing studies, employing the goal programming method in the solution phase. An objective function value of 3 was found, and a balanced schedule was created as much as possible. Koçak et al. (2023) proposed a new arrangement considering the increased workload of nurses during the pandemic, using the goal programming method in their solution. Koçtepe et al. (2019) addressed personnel planning for a basketball match by considering competencies and solving them with the 0-1 integer programming method. Özcan et al. (2020) tackled the scheduling problem of personnel working in hydroelectric power plants, integrating constraint programming and goal programming. Pınarbaşı and Alakaş (2020) proposed a mathematical model for the personnel task scheduling problem using real data and solved it with Excel software, achieving an 85% improvement in workforce efficiency. Yelek et al. (2018) addressed the shift scheduling problem at Kırıkkale University Central Library, developing a goal programming model. Students were assigned to each shift as equally as possible. Uslu et al. (2018) considered the special circumstances of nurses and the imbalances in the current system, addressing the nurse scheduling problem with the 0-1 goal programming method. Üstündağ (2014) tackled the railway crew scheduling problem using a column generation algorithm and random assignment method in the solution phase. Varlı et al. (2017) addressed the exam invigilator assignment problem, developing a goal programming model. Invigilators were assigned in a balanced and fair manner. Yazıcı et al. (2022) addressed the problem of assigning case files to lawyers in a public institution, solving it with the goal programming method. All constraints were met in the model, and the workload distribution was balanced. Yelek et al. (2019) created the work schedule for ANKARAY metro station operation chiefs, solving it with the goal programming method. Since there is no specific study in the literature for station operation chiefs, it has contributed to the literature. Pınarbaşı (2022) addressed the ergonomic personnel scheduling problem in a factory producing medium voltage fuses using the REBA method and constraint programming model. The results showed that the constraint programming model was effective and efficient.

When examining the existing personnel scheduling studies, it is observed that the method predominantly used is the goal programming method. This study focuses on solving the shift scheduling problem in the healthcare sector using the constraint programming method. The proposed constraint programming model introduces a new model to the literature and simultaneously offers a new method that can be used in personnel scheduling. In this context, the study contributes innovation to the literature. The summary table of the literature review is presented in Table 1.

Table 1. Summary of Literature Review

			Methods Used		
Author (Year)	Description	Industry	Integer Programming	Goal Programming	Other
Bedir et al. (2017)	Ergonomic personnel scheduling	Retail		✓	AHP
Bektur and Hasgül (2013)		Service		✓	
Bolayır (2023)	Shift scheduling	Health		✓	
Chu (2007)		Airline		✓	
Ciritcioğlu et al. (2017)	Shift scheduling	Education		✓	
Cürebal et al. (2020)		Organization		✓	AHP
Cürebal and Eren (2021)	Shift scheduling	Health		✓	AHP-TOPSIS
Demirel et al. (2018)		Transportation		✓	
Eren et al. (2021)		Organization		✓	
Fırat and Hurkens (2011)		Service	✓		
Kaçmaz et al. (2020)	Ergonomic personnel scheduling	Production		✓	REBA
Kassa and Tizazu (2013)		Service			Excel solver
Keskinkılıç (2021)		Service	✓		
Koçak et al. (2022)		Health		✓	
Koçak et al. (2023)	Nurse scheduling	Health		✓	
Koçtepe et al. (2018)		Organization	✓		
Koçtepe et al. (2019)		Sports	✓		
Lezaun et al. (2006)		Transportation	✓		
Özcan et al. (2017)	Shift scheduling	Energy		✓	
Özcan et al. (2020)		Energy		✓	Constraint programming

Table 2. Continuation of Literature Review

			Methods Used		
Author (Year)	Description	Industry	Integer Programming	Goal Programming	Other
Özder et al. (2017)		Public		✓	
Pınarbaşı and Alakaş (2020)	Task scheduling	Production			Excel solver
Pınarbaşı (2022)	Ergonomic personnel scheduling	Production			REBA, Constraint programming
Supçiller and Erbilek (2021)	Shift scheduling	Education		✓	AHP
Uslu et al. (2018)	Nurse scheduling	Health		✓	
Ünal and Eren (2016)	Shift scheduling	Service		✓	
Üstündağ (2014)	Team scheduling	Transportation			Column generation algorithm, random assignment method
Varlı et al. (2017)	Examiner assignment	Education		✓	
Yazıcı et al. (2022)	Case file assignment	Law		✓	
Yelek et al. (2018)	Shift scheduling	Education		✓	
Yelek et al. (2019)		Transportation		✓	
This study	Shift scheduling	Health		✓	Constraint programming

5. Case Study

In this study, the optimal assignment of production personnel to existing shifts for a company operating in the healthcare sector in Ankara was examined using the constraint programming model. The application flowchart is shown in Figure 1.

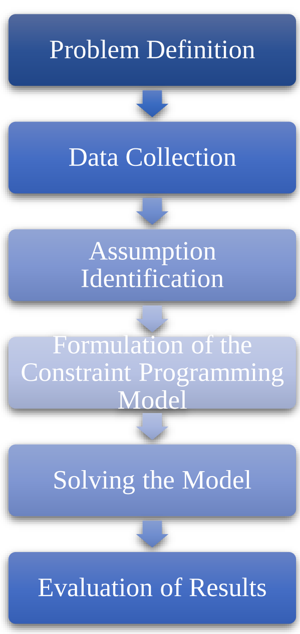

Figure 1. Application Flowchart

5.1. Problem Identification

The primary objective in the healthcare sector is to meet the needs of the community promptly, with high quality, and at low cost. Since the services provided directly impact human health, these services must also be reliable. In this context, for the process to run smoothly from production to distribution, the personnel must be extremely careful, and the factory must operate flawlessly. To prevent personnel from working incorrectly, uncertain and unbalanced situations should be addressed. It has been observed that the shift assignments of the 30 personnel in the production of the mentioned factory are not balanced. To eliminate this issue, it is planned to make a fair assignment considering the demands of both the company and the personnel.

5.2. Data Collection

The data required for solving the problem, such as the number of personnel needed, shift information, and special requests, have been requested from the factory and are provided below:

- The company operates in two shifts. (M: Morning, E: Evening)
- There are 30 personnel.
- The required number of personnel for the morning and evening shifts must be met.
- Personnel numbered 2 and 5 should be assigned only to the morning shift.
- Personnel numbered 3 and 9 should not be assigned to the same shifts.
- Personnel numbered 1 will be on annual leave.

5.3. Assumption Identification

Some assumptions have been made to solve the model. These are provided below:

- The schedule will be made on a monthly basis (31 days).
- Official and religious holidays, as well as weekends, will not be considered.
- The first day in the schedule represents the first day of the month, and the first day of the week represents any day.

5.4. Constraint Programming Model

This section provides the parameters, decision variables, constraints, and objective functions used in the constraint model to solve the problem, along with their descriptions.

<u>Parameters</u>

i: Index of personnel i=1,…,30
j: Index of days j=1,…,31
k: Index of shifts and holidays k=1,…,3

<u>Decision Variables</u>

$x_{ij}: Shift\ number\ assigned\ to\ personnel\ (\ i\ )\ on\ day\ (\ j\ )\quad i = 1,\dots,30\quad j = 1,\dots,31$
$d_{1i}^{+}: Positive\ deviation\ of\ personnel\ (\ i\ )\ from\ the\ total\ monthly\ shifts\quad i = 1,\dots,30$
$d_{1i}^{-}: Negative\ deviation\ of\ personnel\ (\ i\ )\ from\ the\ total\ monthly\ shifts\quad i = 1,\dots,30$
$d_{2ij}^{+}: Positive\ deviation\ of\ personnel\ (\ i\ )\ from\ the\ second\ goal\ on\ day\ (\ j\ )\quad i = 1,\dots,30\quad j = 1,\dots,31$
$d_{2ij}^{-}: Negative\ deviation\ of\ personnel\ (\ i\ )\ from\ the\ second\ goal\ on\ day\ (\ j\ )\quad i = 1,\dots,30\quad j = 1,\dots,31$
$d_{3ij}^{+}: Positive\ deviation\ of\ personnel\ (\ i\ )\ from\ the\ third\ goal\ on\ day\ (\ j\ )\quad i = 1,\dots,30\quad j = 1,\dots,31$
$d_{3ij}^{-}: Negative\ deviation\ of\ personnel\ (\ i\ )\ from\ the\ third\ goal\ on\ day\ (\ j\ )\quad i = 1,\dots,30\quad j = 1,\dots,31$

<u>Constraints</u>

1. Constraint: Each personnel must be assigned to one shift per day. (The form $(x_{ij} = k)$ checks whether the condition inside the parentheses is satisfied. $x_{ij} = 1$ represents the first shift, $x_{ij} = 2$ represents the second shift, and $x_{ij} = 3$ represents the days off).

$$(x_{ij} = 1) + (x_{ij} = 2) \le 1 \quad \forall i, j \tag{3}$$

2. Constraint: The constraint of not assigning personnel on their days off.

$$(x_{ij} = 1) + (x_{ij} = 2) \le 1 - (x_{ij} = 3) \quad \forall i, j \tag{4}$$

3. Constraint: The constraint on the minimum and maximum number of personnel required for the morning and evening shifts each day. (The "$count$" function is used for counting purposes. $count(x_{ij}, k)$ means counting the x_{ij} values that are equal to k).

$$8 \leq count(all\ i)(x_{ij}, 1) \leq 9 \quad j = 1, \dots, 31 \tag{5}$$

$$8 \leq count(all\ i)(x_{ij}, 2) \leq 9 \quad j = 1, \dots, 31 \tag{6}$$

4. Constraint: Personnel numbered 2 and 5 must be assigned only to the morning shift.

$$(x_{2j} \neq 2) \quad \forall j \tag{7}$$

$$(x_{5j} \neq 2) \quad \forall j \tag{8}$$

5. Constraint: Personnel numbered 3 and 9 must not be assigned to the same shifts.

$$(x_{3j} \neq x_{9j}) \quad \forall j \tag{9}$$

6. Constraint: Personnel numbered 1 will be on annual leave from days 7 to 13.

$$(x_{ij} = 3) \quad \forall j = 7, \dots, 13 \tag{10}$$

Defining the Solution Set: The constraint that the decision variable takes integer values between 1 and 3 (x_{ij} being equal to k).
$x_{ij} \in [1,3]$ and integer.

Objectives

Objective 1: Ensure that the total number of shifts assigned to personnel in the monthly work schedule is as equal as possible.

$$count(all\ j)(x_{ij}, 1) + count(all\ j)(x_{ij}, 2) - d_{1i}^{+} + d_{1i}^{-} = 23 \quad i = 1, \dots, 30 \tag{11}$$

Objective 2: When assigning personnel to shifts, ensure that there are no sequences of work day-rest day-work day. (Objective 2 and Objective 3 aim to ensure fairness and continuity in shift assignments).

$$(x_{ij} = 1) + (x_{ij} = 2) + (x_{i(j+1)} = 3) + (x_{i(j+2)} = 1) + (x_{i(j+2)} = 2) - d_{2ij}^{+} + d_{2ij}^{-} = 2 \quad i = 1, \dots, 30 \quad j = 1, \dots, 29 \tag{12}$$

Objective 3: When assigning personnel to shifts, ensure that there are no sequences of rest day-work day-rest day.

$$(x_{ij} = 3) + (x_{i(j+1)} = 1) + (x_{i(j+1)} = 2) + (x_{i(j+1)} = 3) - d_{3ij}^{+} + d_{3ij}^{-} = 2 \quad i = 1, \dots, 30 \quad j = 1, \dots, 29 \tag{13}$$

Objective Function

$$Min\ Z = \sum_{i=1}^{30}(d_{1i}^{+} + d_{1i}^{-}) + \sum_{j=1}^{31}(d_{2ij}^{+} + d_{2ij}^{-} + d_{3ij}^{+} + d_{3ij}^{-}) \tag{14}$$

The objective function involves minimizing the positive and negative deviations in the number of shift days assigned to personnel from the goals.

5.5. Numerical Results

The model was solved using a computer with a 12th Gen Intel(R) Core(TM) i7-12700H processor, 8GB of memory, and the Windows 11 operating system. The established model was solved using the ILOG CPLEX Optimization Studio program. The schedule includes a 31-day schedule for 30 personnel at a factory in Ankara. The existing 2 shifts (M: Morning and E: Evening) and rest (R) days are clearly presented in Table 3. In the table, pink colors (M) represent morning shifts, purple colors (E) represent evening shifts, and green colors (R) represent rest days. Each personnel was assigned to one shift per day, and the required number of personnel for morning and evening shifts was met. Personnel numbered 2 and 5 were assigned only to morning shifts upon their request. Due to a conflict between personnel numbered 3 and 9, they were assigned to different shifts as per their requests. Personnel numbered 1 was granted leave from days 7 to 13.

For personnel numbered 1, the monthly schedule shows morning shifts on days 1, 5, 17, 19, 20, 21, 24, 25, 26, and 27; evening shifts on days 4, 6, 14, 15, 16, 18, 22, and 23; and rest days on days 2, 3, 7, 8, 9, 10, 11, 12, 13, 28, 29, 30, and 31. The objectives were met as much as possible, and an equitable schedule was attempted. The deviation variable d_1^+ took the value of 0, preventing the goal from exceeding the desired value. The deviation variable d_1^- took the values shown in Table 4, indicating that the goal value was lower than expected. The deviation variable d_2^+ took the value of 1 only for the assignment of personnel numbered 8 on day 10, and 0 for other personnel, indicating that the goal was met as much as possible. The values of the deviation variable d_2^- are shown in Table 5, indicating that the goal value was below the expected value. The deviation variable d_3^+ took the value of 1 for the assignment of personnel numbered 15 on day 15, and 0 for other assignments, indicating that the goal was met as much as possible. The values of the deviation variable d_3^- are shown in Table 6, indicating that the goal value was below the expected value. In Tables 4, 5, and 6, P represents Personnel, and D represents Day.

Table 3. Assignment Table

PERSONNEL	DAYS																													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
1	M	R	R	E	M	E	R	R	R	R	R	R	R	E	E	E	M	E	M	M	M	E	E	M	M	M	M	R	R	R	R
2	M	M	M	M	R	R	M	M	M	M	M	M	M	M	M	M	R	R	M	M	M	M	R	R	M	M	M	M	M	R	R
3	M	M	R	R	E	M	R	R	R	R	R	E	E	E	E	M	M	E	M	E	E	E	M	M	R	R	E	E	M	M	E
4	R	M	E	M	E	E	E	M	M	E	R	R	R	E	E	M	M	E	E	M	M	M	E	E	M	R	R	R	R	E	E
5	R	R	R	R	R	R	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	R	R
6	M	R	R	E	M	M	M	E	E	M	E	M	M	M	M	R	R	R	R	R	E	M	E	E	M	M	E	M	M	M	R
7	M	M	M	M	R	R	M	E	R	R	M	E	M	E	M	M	E	M	M	E	E	R	E	E	E	E	R	R	E	E	R
8	M	R	R	M	M	R	R	E	E	E	R	M	E	M	E	E	M	M	E	R	R	R	M	M	M	M	E	E	E	E	R
9	R	R	E	E	R	R	M	E	M	E	E	R	R	M	M	E	E	M	E	M	M	M	E	E	E	E	M	M	E	R	R
10	M	R	R	R	R	E	E	M	R	R	E	M	M	E	E	E	M	E	R	E	E	E	E	E	R	R	E	E	M	R	R
11	E	R	R	R	M	E	M	M	R	R	M	E	R	R	E	M	M	M	E	E	M	M	M	R	R	M	M	M	E	M	E
12	E	E	M	E	M	M	E	E	M	M	R	R	R	M	M	M	E	M	M	E	M	E	R	R	E	E	R	R	R	R	M
13	R	E	M	M	M	M	E	R	R	E	M	M	M	E	M	E	E	R	R	M	E	E	R	R	M	E	E	M	M	E	R
14	R	E	M	E	M	M	R	R	M	M	E	M	E	E	M	M	M	M	M	M	E	M	M	R	R	M	E	M	R	R	R
15	R	R	R	R	M	E	E	E	E	E	M	M	E	R	R	M	R	R	M	E	E	M	M	E	M	E	E	E	M	E	R
16	R	R	R	M	M	M	E	E	E	R	R	E	E	M	M	E	R	R	R	M	E	M	M	M	E	M	M	E	E	E	M
17	E	E	E	E	R	R	R	M	E	M	M	M	E	R	R	E	E	E	R	R	R	R	E	M	E	E	M	M	E	M	M
18	R	R	E	M	E	E	M	M	M	M	E	E	M	R	R	R	E	M	E	M	M	R	R	M	E	E	M	E	M	M	R
19	R	E	M	R	R	R	R	M	E	E	E	E	E	M	E	R	R	E	E	R	R	R	M	M	R	R	R	R	R	R	E
20	E	M	M	E	E	R	R	R	R	R	R	E	E	R	R	R	R	R	E	E	E	R	R	E	M	R	R	R	R	M	M
21	R	M	E	R	R	M	M	R	R	R	E	R	R	R	R	R	R	R	R	R	R	R	R	R	E	M	E	E	M	M	M
22	E	E	M	M	R	R	M	E	R	R	M	E	R	R	R	R	E	M	R	R	R	R	R	E	E	E	E	M	E	E	E
23	R	R	E	E	E	M	R	R	E	E	R	R	M	E	E	E	R	R	R	R	M	E	R	R	R	R	R	E	E	M	E
24	M	M	E	R	R	R	R	R	R	R	R	R	M	E	R	R	R	R	E	E	R	R	R	R	R	R	R	R	R	R	M
25	E	M	R	R	E	E	E	R	R	R	R	R	R	R	R	R	M	E	M	R	R	R	R	R	R	R	R	R	R	R	M
26	E	E	E	R	R	R	R	R	M	M	E	R	R	R	R	R	R	E	E	R	R	R	R	R	R	R	R	R	R	R	E
27	R	R	M	E	R	R	R	E	E	E	R	R	R	R	R	R	R	R	R	R	R	E	E	M	R	R	R	R	R	E	M
28	E	E	R	R	R	E	E	R	R	M	M	R	R	M	E	E	E	R	R	R	R	R	R	R	R	R	R	R	R	R	M
29	E	M	R	R	E	M	E	R	R	R	R	E	E	R	R	R	R	R	R	R	R	E	M	E	E	R	R	R	E	E	E
30	M	E	E	M	E	R	R	M	M	E	R	R	R	R	R	R	E	E	R	R	R	E	E	R	R	E	M	R	R	M	E

Table 4. Values of the Negative Deviation Variable from the First Goal

P	Value
1	5
2	0
3	1
4	0
5	0
6	0
7	0
8	1
9	0
10	3
11	1
12	1
13	0
14	0
15	1
16	0
17	1
18	0
19	8
20	9
21	11
22	5
23	7
24	15
25	14
26	14
27	13
28	12
29	9
30	7

Table 5. Values of the Negative Deviation Variable from the Second Goal

	D																														
P	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
1	0	0	1	0	1	0	1	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0
2	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0	0
3	1	0	0	1	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
4	1	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	0
5	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
6	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0
7	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	1	1	0	0
8	0	0	1	1	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	1	0	0
9	0	1	1	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
10	0	1	1	0	1	0	1	0	0	1	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	1	0	1	0	0	0
11	0	1	0	1	0	0	1	0	0	1	1	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0	1	1	0	1	1	0	0	0
13	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	1	0	1	0	0	1	0	0	0	0	1	0	0
14	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	0	1	0	0
15	1	1	0	1	0	0	0	0	0	0	0	1	0	0	2	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0
16	1	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	1	0	1	0	1	0	0	0	0	1	0	0	1	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0
18	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0
19	1	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	1	1	0	1	0	1	1	0	1	1	1	1	0	0	0
20	0	0	0	1	0	1	1	1	1	0	1	1	0	1	1	1	0	1	0	1	0	0	1	1	0	1	1	0	1	0	0
21	1	1	0	0	1	1	0	1	0	2	0	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	0	0
22	0	0	1	0	0	1	1	0	0	1	1	0	1	1	0	1	1	0	1	1	1	0	1	0	0	0	0	0	0	0	0
23	0	1	0	0	1	0	0	1	1	0	0	1	0	0	1	0	1	1	0	1	1	0	1	1	1	0	1	0	0	0	0
24	0	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	0	0	0
25	1	0	0	1	0	1	0	1	1	1	1	1	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	0	0	0
26	0	1	0	1	1	1	0	1	0	1	0	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	0	0	0
27	0	1	1	0	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	0	1	0	1	0	1	1	1	0	1	0	0
28	1	0	1	0	1	1	0	0	1	1	0	0	1	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0
29	1	0	0	1	0	1	0	1	1	0	1	1	0	1	1	1	1	1	1	0	1	0	0	1	0	1	0	1	0	0	0
30	0	0	0	1	0	0	1	0	1	0	1	1	1	1	0	1	1	0	1	0	1	1	0	0	1	1	0	0	1	0	0

Table 6. Values of the Negative Deviation Variable from the Third Goal

	D																														
P	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
1	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	1	1	0	1	0	1	0	0	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0
3	1	1	0	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	0	1	1	1	0	1	0	0
4	0	1	1	0	0	1	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	0	0
5	0	1	1	1	1	1	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0	1	0	0	0
6	0	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0
7	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	1	0	1	1	1	1	1	1	1	1	0	0	0
8	1	1	0	1	1	0	0	1	1	0	1	1	1	1	1	1	1	1	1	0	2	0	1	1	0	1	1	0	0	0	0
9	1	1	0	0	1	1	0	1	0	2	0	1	1	1	1	1	1	0	1	0	1	0	1	1	1	1	1	1	0	0	0
10	1	0	0	1	1	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0
11	1	0	0	1	0	1	0	1	1	0	1	1	1	1	1	1	0	2	0	1	1	1	0	1	1	0	1	0	1	0	0
12	1	0	1	0	1	1	0	1	1	0	0	1	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1	1	1	0	0
13	1	1	1	1	1	1	1	1	0	1	0	1	0	1	1	1	1	1	1	1	0	1	1	0	0	1	0	0	1	0	0
14	0	1	1	1	1	0	1	1	0	1	1	1	1	1	1	0	1	1	0	1	0	1	1	0	1	1	1	1	0	0	0
15	0	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	1	0	0	0
16	0	0	1	0	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0
17	0	1	0	1	1	1	1	0	1	1	0	1	1	1	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	0	0
18	1	1	0	1	0	1	0	1	1	1	1	0	1	1	0	1	0	1	0	0	1	0	1	1	1	1	1	1	1	0	0
19	1	0	1	1	1	1	1	1	1	1	1	0	1	0	1	0	1	1	1	0	1	1	0	1	1	1	1	1	0	0	0
20	0	0	1	0	0	1	0	1	1	1	1	1	1	0	1	1	0	0	1	0	1	0	0	1	0	0	0	0	1	0	0
21	1	1	1	0	1	0	0	0	0	1	0	0	1	0	0	0	1	0	1	0	1	1	0	0	1	0	0	1	0	0	0
22	0	0	1	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	0	0
23	1	1	0	1	1	0	0	1	1	0	0	1	0	0	1	0	0	1	0	0	0	1	0	1	1	1	1	1	1	0	0
24	1	0	1	1	0	1	1	0	0	1	1	0	1	1	0	1	0	0	1	0	0	1	0	0	0	1	0	1	1	0	0
25	1	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0
26	0	1	1	0	1	0	1	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0
27	1	0	1	0	0	0	1	0	1	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0
28	1	0	0	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	1	0	0	0
29	0	1	0	1	0	0	1	1	0	0	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0
30	0	1	1	0	1	0	1	0	0	1	0	0	1	0	0	0	0	0	0	1	0	1	1	0	1	0	1	0	1	0	0

6. Conclusion and Recommendations

In the healthcare sector, the primary goal is to meet needs with the desired quality, at the desired time, and the lowest cost. Ensuring this flow is uninterrupted is crucial for human health. One of the key aspects of maintaining an error-free flow is the personnel. To prevent personnel from working incorrectly, imbalances and injustices in the system should be addressed. This study addresses the personnel scheduling problem for a factory operating in the healthcare sector in Ankara, aiming to eliminate potential personnel errors and low motivation. A monthly shift schedule was created to assign 30 personnel working in two shifts as fairly as possible. A constraint programming model was established and solved using the ILOG Cplex program. The proposed constraint programming model has been noted in the literature by Pınarbaşı (2022) and Pınarbaşı and Alakaş (2020) to produce promising results.

The model aims to meet the demands of the company and personnel as much as possible, ensuring satisfaction. The 31-day schedule obtained provides a more balanced workload distribution, leading to increased personnel satisfaction. Goal programming is frequently used in solving personnel scheduling problems, and solving this study with constraint programming adds novelty to the literature. As a suggestion for future work, the model can be developed by adding new constraints such as working hours, special skills, and the necessity of a foreman. The model can be developed considering the special requests and demands of the factory or personnel.

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