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APPLICATION OF 0-1 INTEGER GOAL PROGRAMMING FOR SHIFT SCHEDULING OF MEDICAL STAFF IN LABORATORY DEPARTMENT

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ABSTRACT

Shift work is the performance of staff tasks in a specific sequence at specific intervals of equal or different duration so as not to disrupt service or production in an institution or enterprise. With the increase in population, hospitals are the institutions with the most intensive shift work. When scheduling shifts in hospitals, it is difficult to create a balanced shift schedule for each staff by taking into account constraints such as the working conditions of the hospital, the satisfaction of patients, staff and the hospital, and the wishes of staff in terms of days off, holidays , etc. as well as different objectives. Moreover, the cyclical repetition of this scheduling causes a waste of time and psychologically exhausts the staff who prepare schedules. With the help of mathematical models, optimal shift schedules can be prepared in a shorter time and in a simple way, taking into account all constraints and objectives. The aim of this study is to optimally plan the shift schedule for medical staff in the laboratory department. The shift schedule of the laboratory department of a government hospital in Gümüşhane in November 2022 was used for the study. According to the working conditions and shift schedule of the hospital, a 0-1 integer goal programming model is established. The optimal shift schedule was obtained as a result of analyzing the model by coding it in the GAMS 42.5.0 program.

Keywords: *0-1 Integer Goal Programming, Laboratory Department, Medical Staff, Optimization, Shift Scheduling.*

JEL Codes: *C02, C44, C61.*

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LABORATUVAR BİRİMİNDEKİ SAĞLIK PERSONELİNİN VARDİYA ÇİZELGELEMESİNDE 0-1 TAMSAYILI HEDEF PROGRAMLAMA UYGULAMASI

ÖZET

Vardiya, bir kurumda veya bir işletmede verilen hizmetin veya yapılan üretimin aksamaması için personelin eşit veya farklı sürelerdeki belirli zaman aralıklarında, belirli bir sıraya göre görevlerini yürütmeleridir. Nüfustaki artış ile birlikte en yoğun vardiyalı çalışan kurumlar hastanelerdir. Hastanelerde vardiya çizelgelemeleri yapılırken; hastanenin çalışma şartları, hastanın, personelin ve hastanenin memnuniyetleri, personelin izin, tatil vb. tercihleri gibi kısıtların yanı sıra farklı hedeflerin dikkate alınarak her personel için dengeli bir vardiya çizelgesinin yapılması zor olmaktadır. Üstelik bu çizelgelemenin döngüsel olarak tekrar hazırlanması zaman kaybına yol açarken çizelgeleri hazırlayan personeli de zihinsel olarak yormaktadır. Tüm kısıtlar ve hedefler göz önünde bulundurularak matematiksel modeller yardımıyla optimal vardiya çizelgeleri daha kısa zamanda ve kolay bir şekilde hazırlanabilmektedir. Bu çalışmanın amacı, laboratuvar birimindeki sağlık personelinin vardiya çizelgesinin optimal planlanmasıdır. Çalışmada; Gümüşhane ilindeki bir devlet hastanesinin laboratuvar biriminin Kasım 2022 vardiya çizelgesi kullanılmıştır. Hastanenin çalışma şartlarına ve vardiya çizelgesine göre 0-1 tamsayılı hedef programlama modeli kurulmuştur. Modelin GAMS 42.5.0 programında kodlanarak çözümlenmesi sonucunda optimal vardiya çizelgesi elde edilmiştir.

Anahtar Kelimeler: *0-1 Tamsayılı Hedef Programlama, Laboratuvar Birimi, Sağlık Personeli, Optimizasyon, Vardiya Çizelgeleme.*

JEL Kodları: *C02, C44, C61.*

1. INTRODUCTION

Shift scheduling is the assignment of a certain number of staff to shifts and days off in order to fully meet the demand for staff on shift and to establish the working order (Stolletz and Brunner, 2012: 622). Shift scheduling of nurses, doctors or medical staff consists of staff assignments that must be made in a certain order within a certain time interval of equal or different durations for the execution of the service provided in a hospital or a department of the hospital. The shifts of the staff are divided into certain time intervals in order to prevent the flow of the service provided in hospitals and to obtain the necessary efficiency from the medical staff. In hospitals, shift scheduling of medical staff is carried out in a certain order for the shifts allocated according to different time intervals in equal or different durations, such as morning, evening, night, full day, etc. It is difficult for the staff who prepare shift schedules to manually prepare a shift schedule that is efficient for the hospital, patients and staff, taking into account the working conditions of the hospital, working regulations, the number of staff required to be in the shift, the competence of the staff, the limitations of the staff such as days off, preferences, seniority levels, etc., and the goals set for the hospital, the department in the hospital and the staff. Repreparation of these manually prepared shift schedules over a period of time tires the staff who prepare them mentally while causes a loss of time for these staff. In addition, as the constraints and goals for shift scheduling increase, the work of the staff preparing the shift schedule becomes more difficult. Efficient and fair shift schedules that meet all the desired constraints and goals, where the workforce is used effectively and service quality is increased, can be prepared with the help of mathematical models. Moreover, shift schedules prepared using mathematical models are obtained in a shorter time and are optimal compared to manually prepared shift schedules. Shift schedules prepared in this way make hospitals more efficient by increasing their performance, providing a fairer and more efficient workload for the staff and cost minimization.

The shift scheduling problem of medical staff in hospitals is a combinatorial optimization problem. Studies are mainly concerned with the departments in hospitals and the scheduling problem of nurses in these departments. In these studies; mixed integer, 0-1 integer, goal programming models are established by considering some hard and soft constraints in line with the legal working conditions determined by the state, the working principles of the hospital, and the preferences of the staff in shift schedule. Exact and heuristic algorithms are used in solving these set-up models (Stolletz and Brunner, 2012; Tan et al., 2019: 2).

For this study, the laboratory department of a state hospital in Gümüşhane was determined for the optimal planning of one-month shift schedule of the medical staff in the laboratory department of a state hospital. A 0-1 integer goal programming model was established according to the working conditions in the hospital and the laboratory department and the shift schedule of the medical staff in the laboratory department in November 2022. GAMS 42.5.0 program was used for coding and solving the set-up model. As a result, one-month shift schedule of the laboratory department was obtained optimally.

2. LITERATURE REWIEW

Numerous studies on personnel scheduling can be found in the literature. These studies have been carried out using different methods to solve scheduling problems in different sectors. In the literature search, it was found that the studies on personnel scheduling were mostly conducted in the health field for nurses' scheduling problems in hospitals with one or both of mathematical and heuristic methods used in these studies.

The oldest study in the literature on nurses' scheduling problems is Taylor's (1940), the first study to use a mathematical model for these problems is Wolfe and Young's (1965), and the first study to use objectives with more than one option in a mathematical model is Warner's (1976). The objective of Taylor's (1940) study was to improve nurses' schedule by determining nurses' schedule preferences from a questionnaire prepared as part of the continuing in-service program conducted between October 1938 and June 1939 for nurses at Massachusetts General Hospital. Wolfe and Young (1965) published their study in two parts, part I and part II. They used controlled variable staffing in part I and the multiple assignment technique in part II. In part II, they created a mathematical model to minimize the cost of assigning nurses to various tasks. In his study, Warner (1976) presented a multiple-choice programming problem to define a nurse scheduling system that measures nurses' preferences regarding the length of their working time, rotation patterns and day off requests.

Regarding the subject of the study, literature summary of studies categorized by methods used in solving personnel or shift scheduling problems in hospitals is given below:

- Linear programming method: Kumar et al. (2014)
- Integer programming method:
  - ❖ 0-1 integer linear programming: Jaumard et al. (1998), Moz and Pato (2004), Narlı and Oğulata (2008), Öztürkoğlu and Çalışkan (2014), Hidri and Labidi (2016), Karayel and Atmaca (2017), Horvat et al. (2020), Bektur et al. (2023)
  - ❖ Mixed integer linear programming: Ogulata et al. (2008), Brunner et al. (2009), Stolletz and Brunner (2012), Bruni and Detti (2014), Smalley et al. (2015), Keskin et al. (2020)
  - ❖ Mixed integer quadratic programming: Warner and Prawda (1972)
  - ❖ Integer linear programming: Güngör (2002), Seçkiner and Kurt (2005)
  - ❖ Nonlinear integer programming: Li and Kozan (2009)
- Goal programming and multi-objective programming method:
  - ❖ 0-1 integer goal programming: Franz et al. (1989), Huarng (1999), Azaiez and Al Sharif (2005), Jenal et al. (2011), Atmaca et al. (2012), Ismail and Jenal (2013), Wang et al. (2014), Agyei, et al. (2015), Sulak and Bayhan (2016), Varlı and Eren (2017), Al-Hinai et al. (2018), Özcan et al. (2019), Nasir et al. (2021), Al-Mudahka and Alhamad (2022), Bayraktar and Aytaç Adalı (2022)
  - ❖ Mixed integer goal programming: Trivedi (1981)
  - ❖ Mixed-integer sequential goal programming: Ang et al. (2018)
  - ❖ Integer goal programming: Ozkarahan and Bailey (1988)
  - ❖ Goal programming: Musa and Saxena (1984), Chae et al. (1985), Elomri et al. (2015), Rerkjirattikal et al. (2020)
  - ❖ Preemptive goal programming: Lim et al. (2012) a two-stage non-weighted goal programming, Sundari and Mardiyati (2017)
  - ❖ Multi-objective programming: Topaloglu (2009), Chiang et al. (2019)
- Hybrid methods:
  - ❖ Bertels and Fahle (2006) linear programming, constraint programming and meta-heuristic
  - ❖ In addition to 0-1 integer linear programming, Aickelin and White (2004) evolutionary algorithms and statistical comparison method, Trilling et al. (2006) constraint programming, Liu et al. (2018) simulated annealing

- ❖ In addition to mixed integer linear programming, Brunner and Edenharter (2011) heuristic, Woodall et al. (2013) simulation, Azadeh et al. (2014) and Azadeh et al. (2015) genetic algorithm, Geçici and Güler (2020) decision support system
- ❖ In addition to integer linear programming, Dowsland and Thompson (2000) tabu search, Burke et al. (2010) variable neighbourhood search method, Anderson et al. (2023) heuristic algorithm
- ❖ In addition to 0-1 integer goal programming, Arthur and Ravindran (1981) heuristic, Ozkarahan (1991) assignment model, Chen and Yeung (1993) expert system, Topaloglu (2006) and Chen et al. (2016) analytic hierarchy process (AHP), Bağ et al. (2012) analytic network process (ANP)
- ❖ In addition to goal programming, Güler et al. (2013) AHP, Hakim et al. (2017) nonlinear optimization, Gür et al. (2022) constraint programming
- ❖ Karaatlı and Güngör (2010) fuzzy multi-objective linear programming and heuristic assignment algorithm, Topaloglu and Selim (2010) multi-objective integer programming and fuzzy goal programming, Tan et al. (2019) mixed integer multi-objective programming and AHP.

The literature summary of the studies carried out according to the application areas for personnel or shift scheduling problems in hospitals is given below:

- Ambulance Crew: Li and Kozan (2009), Horvat et al. (2020)
- Anesthesia Department: Trilling et al. (2006) anaesthesiology nurses, Brunner et al. (2009) physicians in the anesthesia department of a university hospital, Brunner and Edenharter (2011) physicians in the anesthesia department
- Cardiology Department: Bektur et al. (2023) considering physicians who are radiation exposure in the cardiology department of a public hospital
- Cardiovascular Surgery Service: Geçici and Güler (2020) cardiovascular surgery service nurses
- Coronary Care Unit: Nasir et al. (2021) nurses in coronary care unit of a hospital
- Emergency Department: Topaloglu (2006) emergency medicine residents, Al-Hinai et al. (2018) nurses, Ang et al. (2018) nurses, Tan et al. (2019) physicians in emergency department of a university hospital
- General Surgery Department: Karaatlı and Güngör (2010) nurses in surgery department of a university hospital
- Hemodialysis Service: Liu et al. (2018) nurses in a hemodialysis service
- Home Health Care: Bertels and Fahle (2006) home health care staff, Anderson et al. (2023) nurses
- Intensive Care Unit: Narlı and Oğulata (2008) nurses in intensive care unit of a university, Burke et al. (2010) nurses in intensive care units in a hospital, Öztürkoğlu and Çalışkan (2014)

intensive care nurses in surgery department of a university hospital, Hidri and Labidi (2016) physicians in an intensive care unit

- Laboratory Department: Azadeh et al. (2014) patients scheduling in an emergency department laboratory, Azadeh et al. (2015) semi-online patient scheduling in a pathology laboratory
- Nurse: Warner and Prawda (1972), Arthur and Ravindran (1981), Musa and Saxena (1984), Ozkarahan and Bailey (1988), Ozkarahan (1991), Chen and Yeung (1993), Jaumard et al. (1998), Huarng (1999), Dowsland and Thompson (2000), Güngör (2002), Aickelin and White (2004), Moz and Pato (2004), Azaiez and Al Sharif (2005), Topaloglu and Selim (2010), Jenal et al. (2011), Atmaca et al. (2012), Bağ et al. (2012) nurses and medical staff in urology service and ear, nose and throat (ENT) service of a hospital, Lim et al. (2012), Ismail and Jenal (2013), Kumar et al. (2014), Sulak and Bayhan (2016) blood bank centre nurses, Hakim et al. (2017), Karayel and Atmaca (2017), Sundari and Mardiyati (2017), Varlı and Eren (2017) intensive care nurses, operating room and emergency departments of a hospital, Keskin et al. (2020) nurses in emergency and intensive care departments
- Oncology Department: Woodall et al. (2013) different types of nurses during oncology treatment causes at a cancer institute
- Operating Room: Chiang et al. (2019) simultaneous nursing unit and operating room scheduling, Rerkjirattikal et al. (2020) nurses in operating room of a hospital, Gür et al. (2022) surgical team in operating room
- Outpatient Department: Wang et al. (2014) outpatient department nurses, Agyei et al. (2015) nurses at the outpatient department of a government hospital
- Pediatric Emergency Department: Bayraktar and Aytaç Adalı (2022) nurses in pediatric emergency department of a hospital
- Pediatric Intensive Care Unit: Smalley et al. (2015) assigning physicians to service and call shifts in pediatric intensive care unit of a children's hospital
- Physician: Topaloglu (2009) medical residents in different clinical settings of a hospital, Stolletz and Brunner (2012) physicians, Güler et al. (2013) medicine residents in anesthesia and reanimation department of a private university, Bruni and Detti (2014) physicians in department of cellular biotechnology and hematology of a university hospital, Elomri et al. (2015) medicine residents in oncology and hematology departments in a health care clinic
- Physiotherapy Service: Ogulata et al. (2008) physiotherapist and patient scheduling at a university hospital
- Radiology Department: Seçkiner and Kurt (2005) radiography technicians, Chen et al. (2016) emergency room radiological technologists in a hospital image center, Özcan et al. (2019) radiology technicians in a private hospital, Al-Mudahka and Alhamad (2022) radiologists in radiology department of a hospital

- Other: Trivedi (1981) budgeting in a hospital nursing department, Chae et al. (1985) a capital investment for a state-owned, university-based, teaching hospital, Franz et al. (1989) scheduling and staffing multiple clinics with itinerant medical staff in multiclinic regions.

From the literature review, it appears that many studies on shift scheduling in many departments of the hospital have been conducted using mathematical methods. On the other hand, there is no study in the literature on the optimization of shift scheduling of medical staff in the laboratory department of the hospital, which is the subject of this study, using mathematical method/methods. For this reason, this study is expected to contribute to the literature in the field of operations.

3. GOAL PROGRAMMING METHOD

The goal programming method is one of the multicriteria decision techniques used to find an optimal solution for decision problems with conflicting objectives (Özcan et al., 2019: 1413).

In the goal programming method based on linear programming, more than one objective is formulated as constraints and an attempt is made to minimize the sum of absolute deviations of the objective functions from these objectives. The main difference between the linear programming method and the goal programming method is that the linear programming method allows for a single goal, while the goal programming method allows for multiple goals to be considered simultaneously (Ahern and Anandarajah, 2007: 70; Ignizio, 1985). In other words, the goal programming method does not minimize or maximize the goal directly like the linear programming method, but tries to minimize the deviations between the desired goals and the actual results (Rifai, 1996: 41).

The goal programming method was first introduced by Charnes, Cooper, and Ferguson in 1955. In this study, Charnes, Cooper, and Ferguson referred to goal programming as constrained regression. Subsequently, goal programming was clearly defined for the first time by Charnes and Cooper in 1961 (Charnes et al., 1955; Charnes and Cooper, 1961; Ignizio, 1985: 12). In the studies carried out from the mid-1970s to the present day, it has been a method that has been developed and effectively used by applying it in many different fields and sectors in terms of its applicability to real life (Ignizio, 1985: 9; Girginer and Kaygısız, 2009: 218).

In general, the mathematical representation of the goal programming model is expressed as follows (Charnes and Cooper, 1977: 41):

Objective function:

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

Constraints:

$$\sum_{j=1}^{n} a_{ij}x_j + d_i^- - d_i^+ = b_i, i = 1,2,\dots,m \quad (2)$$

$$x_j, d_i^-, d_i^+ \geq 0, i = 1,2,\dots,m, j = 1,2,\dots,n \quad (3)$$

The explanations of the variables used in the above goal programming model are given below (Varlı and Eren, 2017: 35):

Min Z: Minimized objective function

x_j: j-th decision variable

a_{ij}: Coefficient of the j-th decision variable of the i-th goal

b_i: Desired value to achieve for the i-th goal

d_i^-: Negative deviation variable of the i-th goal

d_i^+: Positive deviation variable of the i-th goal

The most commonly used goal programming methods in the literature, as stated by Charnes and Cooper, are given below (Ignizio, 1985: 12-13):

1. Archimedean goal programming (weighted or minsum goal programming): In Archimedean goal programming, the (weighted) sum of all undesirable absolute deviations from the goals is minimized.
2. Chebyshev goal programming (minmax goal programming): In Chebyshev goal programming, the maximum of undesirable goal deviations is minimized.
3. non-Archimedean goal programming (lexicographic or preemptive priority goal programming): In non-Archimedean goal programming, the lexicographic minimum of an ordered vector of undesirable goal deviations is sought.

There are three different methods for solving goal programming problems. These methods are (Acharya et al., 2011: 54):

- Graphical method applied to problems with two or three variables
- Sequential goal programming method
- Multi-phase simplex method

Goal programming models are mathematical models with a large number of variables. Many companies have developed commercial and non-commercial programs for solving mathematical models with a large number of variables with the development of computer technology. The solution of goal programming models can be done in a short time by using programs such as Excel Solver, LINGO, LINDO, GAMS, CPLEX, etc. In this present study, GAMS program was used to code and solve the 0-1 integer goal programming model for optimal shift scheduling of medical staff in the laboratory department.

4. APPLICATION OF 0-1 INTEGER GOAL PROGRAMMING

The study was conducted in the laboratory department of a state hospital in Gümüşhane. A 0-1 integer goal programming model was established according to the working conditions determined by the hospital and the one-month shift schedule of the medical staff in the laboratory department (These medical staff consist of health technicians, health officers-laboratory technicians, biologists). This model was coded and solved in GAMS program. As a result of the solution of the model, a shift schedule that is fair in the distribution of work for the medical staff and efficient for the medical staff and the hospital was created.

Laboratory department is one of the busy departments in hospitals. Because the data of all outpatients and inpatients admitted to the hospital are studied in the laboratory department, as the circulation of other departments increases, the circulation of the laboratory department increases proportionally. Therefore, the laboratory department is a busy department with patient circulation 24/7.

The laboratory department is divided into different areas according to the applications performed. The order of the areas in the laboratory department according to the patient's data such as blood, urine, stool, biopsy, body fluids is given below:

- Blood Gas-Sample Separation: In this area, blood gas samples are accepted and studied.
- Sample Acceptance: It is the area that classifies, separates and records all samples coming to the laboratory department. (Not included in shift schedule in the laboratory department.)
- Urine: It is the area that analyzes all urine samples taken from patients.
- Biochemistry: It is the area that performs biochemistry analyses of blood samples taken from patients.
- Hormone: It is the area that performs hormone analyses of blood samples taken from patients.
- Transfusion & Sedimentation: It is the area responsible for performing serologic tests to be performed before blood transfusion, blood group determination, procurement of blood from the Red Crescent, storage of the procured blood under appropriate conditions, transfer and transfer of the transfusion to the service.
- Microbiology: It is the area that analyzes samples taken from patients such as culture and peripheral smear.
- Hemogram & Coagulation: It is the area that performs hemogram and coagulation analyses of blood samples taken from patients.

There are eleven health technicians-laboratory (one of these eleven staff is in charge of the laboratory department), five health officers-laboratory technicians, one biologist in the laboratory department of the state hospital where the application was made. Apart from these staff, there is one biologist, one storekeeper (health technician), one health technician working in the sample acceptance area and these staff are not included in the shift schedule in the laboratory department. Of the seventeen medical staff in the shift schedule in the laboratory department, sixteen medical staff, excluding the laboratory supervisor, perform the duties in the 8-hour shifts of 08:00-16:00 and 24-hour shifts of 08:00-08:00 without any discrimination between the staff. In case of overcrowding in the areas of the laboratory department in the shift schedule, these sixteen staff are called to the 08:00-16:00 shift as support staff. The laboratory supervisor, who is one of the seventeen medical staff in the shift schedule, is responsible for the functioning of all areas of the laboratory department and the supply of equipment, maintenance-repair and materials every weekday, which is called the laboratory supervisor shift. This laboratory supervisor comes on 08:00-16:00 shift every weekday and when necessary, they are on duty for 24 hours in 08:00-08:00 shift.

In each area (blood gas-sample separation, sample acceptance, urine, biochemistry, hormone, transfusion & sedimentation, microbiology, hemogram & coagulation) in the laboratory department of the state hospital in practice, medical staff are assigned every weekday 08:00-16:00 shift with one or two staff depending on the intensity in the area. In the 08:00-08:00 shift every weekday, medical staff are assigned to an area in the laboratory department in the first 08:00-16:00 time period of 24 hours, and in the remaining 16:00-08:00 time period, two medical staff jointly take care of all areas in the laboratory department. On the weekend, two medical staff share all areas in the laboratory department during the 08:00-08:00 shift.

Apart from the designated areas in the laboratory department, a PCR laboratory was established due to the Covid-19 outbreak, which was declared as a pandemic between 2020-2022, and one biologist was assigned to this area. Only PCR tests are performed in this area and there is an 08:00-16:00 shift. The space and biologist in this laboratory department are not included in the shift schedule.

Other medical staff not included in the shift schedule in the laboratory department are the storekeeper (health technician) and the health technician working in the sample acceptance area. The storekeeper assigned in the warehouse area of the laboratory department is responsible for the supply of medical consumables for the laboratory, the organization, storage and sorting of medical supplies, distribution to services as needed, technical support and maintenance of medical devices. The health technician assigned in the sample acceptance area is in charge of accepting incoming patient samples to the laboratory department and delivering them to the relevant laboratory area.

4.1. Ethical Approval

The functioning and information in the laboratory department of the state hospital determined for the application, the November 2022 shift schedule of the medical staff in the laboratory department were obtained from the laboratory supervisor in the laboratory department of the hospital after obtaining permission as per the decision of Gümüşhane University Scientific Research and Publication Ethics Board dated 12/27/2022 and numbered 2022/7, and the decision of Gümüşhane Provincial Health Directorate dated 01/13/2023 and numbered E-51020271-044-207023258.

4.2. Shift Scheduling Problem in Laboratory Department

As in every department of the hospital, it is aimed to create a fair schedule for each staff in the shift scheduling of the medical staff in the laboratory department. However, in Table 1, which is the November 2022 shift schedule of the medical staff in the laboratory department of the state hospital determined for the application, it is seen that the shifts among the medical staff are not fair. In addition, there are no medical staff in the laboratory department of the hospital who took the day off for the whole month in November 2022.

According to the legal working conditions determined by the state hospital determined for the application, the operation and information in the laboratory department, the shift schedule of the medical staff in the laboratory department in November 2022, a 0-1 integer goal programming model was established and the GAMS program was used in the coding and analysis of the established model. As a result of the solution of the model, an efficient and fair optimal shift schedule has been created for the medical staff in the laboratory department.

The working conditions of the state hospital and the laboratory department where the application took place were determined by the hospital as follows:

- In each department of the hospital, the number of medical staff varies according to the shift. According to the legal conditions, the weekly working time of each medical staff in the hospital is at least 40 hours. According to the shift schedule in the laboratory department, in November 2022, each of the medical staff should work at least 22*8=176 hours. (There are 22 weekdays in November 2022. 08:00-16:00 shift duration is 8 hours on weekdays). In addition, in November 2022 in Table 1, the 7th medical staff who take 18 days off should work at least 64 hours, and the 10th, 11th and 13th medical staff who take 5 days off should work at least 136 hours.
- Each medical staff except the laboratory supervisor in the laboratory department of the hospital should work only in one of the blood gas-sample separation, sample acceptance, urine, biochemistry, hormone, transfusion & sedimentation, microbiology, hemogram & coagulation areas (08:00-16:00 on weekdays) on the day specified in the shift schedule.

- Medical staff working as laboratory supervisors in the hospital's laboratory department must also work the laboratory supervisor shift (08:00-16:00 every weekday). Other staff cannot work this shift.
- The number of medical staff varies in the different areas of the laboratory department of the hospital. Medical staff must be present in the laboratory department, every weekday from 08:00-16:00: one in the blood gas-sample separation area, one in the urine area, two in the biochemistry area, two in the hormones area, minimum one and maximum two in the transfusion and sedimentation area, two in the microbiology area, one in the haemogram and coagulation area.
- In the laboratory department, two medical staff should work in the 16-hour laboratory shift, i.e. every weekday from 16:00-08:00.
- In the laboratory department, two medical staff should work in the 24-hour laboratory shift, i.e. every weekend day from 08:00-08:00.
- After the 08:00-16:00 shift of the medical staff in the laboratory department, if they are on duty in the 08:00-08:00 shift that day, they can work in the laboratory during the remaining time from 16:00-08:00 or be assigned to the 08:00-16:00 shift or 08:00-08:00 shift the next day.
- After the 08:00-16:00 shift of the medical staff in the laboratory department, there may be a maximum of three days of unexcused break between shift days.
- Medical staff in the laboratory department must take a 24-hour rest period after 16-hour laboratory shifts with a 16:00-08:00 shift and 24-hour laboratory shifts with a 08:00-08:00 shift. Although this varies according to the hospital's administrative regulations, there may be a maximum of three days of unexcused break between medical staff shift days.
- The sum of 8-hour shifts (except for the laboratory supervisor, 16-hour shifts and 24-hour shifts of each medical staff within a month should be as equal as possible.

4.3. 0-1 Integer Goal Programming Model for Shift Scheduling Problem in Laboratory Department

The 0-1 integer goal programming model was set up in accordance with the hospital's working conditions, number and shifts of medical staff in the November 2022 shift schedule of medical staff in the hospital's laboratory department identified for the application. The 0-1 whole number goal programming model established for the optimal November shift schedule of medical staff in the hospital's laboratory department is given below.

Indices and sets:

i: Medical staff in the laboratory department of the hospital: i = 1, 2, ... , 17 (17th staff is the laboratory supervisor).

j: Days in November 2022: j = 1, 2, ... , 30

A: Set of weekdays A={1,2,3,4,7,8,9,10,11,14,15,16,17,18,21,22,23,24,25,28,29,30}

B: Set of weekend days B={5,6,12,13,19,20,26,27}

k: Shifts in the laboratory department of the hospital: k= 1, 2, ... , 10 (According to the shift schedule of the hospital, the shifts are respectively; 1: blood gas-sample separation, 2: urine, 3: biochemistry, 4: hormone, 5: transfusion & sedimentation, 6: microbiology, 7: haemogram & coagulation (the areas numbered 1-7 are 08:00-16:00 on weekdays), 8: 16-hour laboratory shift (if the medical staff is also on duty in the 08:00-08:00 shift that day after the 08:00-16:00 shift on weekdays, the remaining 16:00-08:00 shift), 9: 24-hour laboratory shift (08:00-08:00 on weekends), 10: laboratory supervisor shift (08:00-16:00 on weekdays).)

Decision variables:

$$x_{ijk}: \begin{cases} 1, & if\ i.medical\ staff\ works\ a\ k.shift\ in\ j.day, \\ 0, & otherwise, \end{cases} \quad i = 1,2,\ldots,17, j = 1,2,\ldots,30, k = 1,2,\ldots,10$$

$$\mathrm{t_{ij}}: \begin{cases} 1, & if\ i.medical\ staff\ took\ the\ day\ off\ for\ j.day, \\ 0, & otherwise, \end{cases} \quad i = 1,2,\ldots,17, j = 1,2,\ldots,30$$

Goal deviation variables:

d_i^-: Negative deviation from the goal of the total number of shifts of the i-th medical staff (excluding the laboratory supervisor, i = 1, 2, ... ,16) in the areas numbered 1-7

d_i^+: Positive deviation from the goal of the total number of shifts of the i-th medical staff (excluding the laboratory supervisor, i = 1, 2, ... ,16) in the areas numbered 1-7

e_i^-: Negative deviation from the goal of the total number of shifts of the i-th medical staff (i = 1, 2, ... ,17) in the 16-hour laboratory shift numbered 8

e_i^+: Positive deviation from the goal of the total number of shifts of the i-th medical staff (i = 1, 2, ... ,17) in the 16-hour laboratory shift numbered 8

f_i^-: Negative deviation from the goal of the total number of shifts of the i-th medical staff (i = 1, 2, ... ,17) in the 24-hour laboratory shift numbered 9

f_i^+: Positive deviation from the goal of the total number of shifts of the i-th medical staff (i = 1, 2, ... ,17) in the 24-hour laboratory shift numbered 9

Objective function:

$$Z_{min} = \sum_{i=1}^{16}(d_i^- + d_i^+) + \sum_{i=1}^{17}(e_i^- + e_i^+ + f_i^- + f_i^+) \quad (4)$$

Constraints:

Constraint 1: Each medical staff in the laboratory department of the hospital must work at least 176 hours in November 2022 (17th staff member is the laboratory supervisor).

$$8\sum_{j=1}^{30}\sum_{k=1}^{7}x_{ijk}+16\sum_{j=1}^{30}x_{ij8}+24\sum_{j=1}^{30}x_{ij9}\geq 176, i=1,2,\ldots,16 \quad (5)$$

$$8\sum_{j=1}^{30}x_{17j10}+16\sum_{j=1}^{30}x_{17j8}+24\sum_{j=1}^{30}x_{17j9}\geq 176 \quad (6)$$

Constraint 2: Each medical staff in the laboratory department of the hospital, except the laboratory supervisor, should work only in one of the areas numbered 1-7 and 9 on the day determined in the shift schedule. The laboratory supervisor must also work only in one of the areas numbered 9 and 10.

$$\sum_{k=1}^{7}x_{ijk}+x_{ij9}\leq 1, i=1,2,\ldots,16, j=1,2,\ldots,30 \quad (7)$$

$$\sum_{k=9}^{10}x_{17jk}\leq 1,\ j=1,2,\ldots,30 \quad (8)$$

Constraint 3: In the laboratory department, 1 medical staff should work in the blood gas-sample separation area (08:00-16:00 on weekdays). (There is no laboratory supervisor in this area.)

$$\sum_{i=1}^{16}x_{ij1}=1, j\in A \quad (9)$$

Constraint 4: In the laboratory department, 1 medical staff should work in the urine area (08:00-16:00 on weekdays). (There is no laboratory supervisor in this area)

$$\sum_{i=1}^{16}x_{ij2}=1, j\in A \quad (10)$$

Constraint 5: In the laboratory department, 2 medical staff should work in the biochemistry area (08:00-16:00 on weekdays). (There is no laboratory supervisor in this area.)

$$\sum_{i=1}^{16}x_{ij3}=2, j\in A \quad (11)$$

Constraint 6: In the laboratory department, 2 medical staff should work in the hormone area (08:00-16:00 on weekdays). (There is no laboratory supervisor in this area)

$$\sum_{i=1}^{16} x_{ij4} = 2, j \in A \tag{12}$$

Constraint 7: At least 1 and at most 2 medical staff must work in the transfusion & sedimentation area (08:00-16:00 on weekdays) in the laboratory department. (There is no laboratory supervisor in this area.)

$$\sum_{i=1}^{16} x_{ij5} \geq 1, j \in A \tag{13}$$

$$\sum_{i=1}^{16} x_{ij5} \leq 2, j \in A \tag{14}$$

Constraint 8: In the laboratory department, 2 medical staff should work in the microbiology area (08:00-16:00 on weekdays). (There is no laboratory supervisor in this area.)

$$\sum_{i=1}^{16} x_{ij6} = 2, j \in A \tag{15}$$

Constraint 9: In the laboratory department, 1 medical staff should work in the haemogram & coagulation area (08:00-16:00 on weekdays). (There is no laboratory supervisor in this area)

$$\sum_{i=1}^{16} x_{ij7} = 1, j \in A \tag{16}$$

Constraint 10: In the laboratory department, 2 medical staff should work in the 16-hour laboratory shift (16:00-08:00 on weekdays).

$$\sum_{i=1}^{17} x_{ij8} = 2, j \in A \tag{17}$$

Constraint 11: In the laboratory department, 2 medical staff should work in the 24-hour laboratory shift (08:00-08:00 on weekends).

$$\sum_{i=1}^{17} x_{ij9} = 2, j \in B \tag{18}$$

Constraint 12: Only 17th medical staff should be assigned to the laboratory supervisor shift (08:00-16:00 on weekdays) in the laboratory department.

$$\sum_{k=1}^{7} x_{17jk} = 0, j \in A$$
$$x_{ij10} = 0, i = 1,2, \ldots, 16, j = 1,2, \ldots, 30 \quad (19)$$

Constraint 13: The 17th medical staff who is the laboratory supervisor in the laboratory department must be on laboratory supervisor shift every weekday (except the day after 16 and 24 hour laboratory shifts).

$$x_{17j10} + x_{17(j+1)10} \geq 1, j = 1,2, \ldots, 29 \quad (20)$$

Constraint 14: Each medical staff in the laboratory department should not work the day after 16 and 24 hour laboratory shifts (17th staff is the laboratory supervisor).

$$x_{ij8} + \sum_{k=1}^{9} x_{i(j+1)k} \leq 1, i = 1,2, \ldots, 16, j = 1,2, \ldots, 29 \quad (21)$$

$$x_{ij9} + \sum_{k=1}^{9} x_{i(j+1)k} \leq 1, i = 1,2, \ldots, 16, j = 1,2, \ldots, 29 \quad (22)$$

$$x_{17j8} + \sum_{k=8}^{10} x_{17(j+1)k} \leq 1, j = 1,2, \ldots, 29 \quad (23)$$

$$x_{17j9} + \sum_{k=8}^{10} x_{17(j+1)k} \leq 1, j = 1,2, \ldots, 29 \quad (24)$$

Constraint 15: Every medical staff in the laboratory department must not work on the day off.

$$t_{ij} + \sum_{k=1}^{10} x_{ijk} = 1, i = 1,2, \ldots, 17, j = 1,2, \ldots, 30 \quad (25)$$

Constraint 16: Each medical staff in the laboratory department may have a maximum of 3 days break between shift days without excuse.

$$t_{ij} + t_{i(j+1)} + t_{i(j+2)} + t_{i(j+3)} \leq 3, i = 1,2, \ldots, 17, j = 1,2, \ldots, 27 \quad (26)$$

Constraint 17: In the November shift schedule in the laboratory department, the 7th medical staff should not be on any shift on days 1-18.

$$\sum_{k=1}^{9} x_{7jk} = 0, j = 1,2, \dots ,18 \tag{27}$$

Constraint 18: In the November shift schedule in the laboratory department, the 10th medical staff should not be on any shift on days 14-18.

$$\sum_{k=1}^{9} x_{10jk} = 0, j = 14,15, \dots ,18 \tag{28}$$

Constraint 19: In the November shift schedule in the laboratory department, the 11th medical staff should not be on any shift on days 14-18.

$$\sum_{k=1}^{9} x_{11jk} = 0, j = 14,15, \dots ,18 \tag{29}$$

Constraint 20: In the November shift schedule in the laboratory department, the 13th medical staff should not be on any shift on days 7-11.

$$\sum_{k=1}^{9} x_{13jk} = 0, j = 7,8, \dots ,11 \tag{30}$$

Constraint 21:

$$d_i^-, d_i^+ \geq 0 \text{ and integer}, i = 1,2, \dots ,16 \tag{31}$$

$$e_i^-, e_i^+, f_i^-, f_i^+ \geq 0 \text{ and integer}, i = 1,2, \dots ,17 \tag{32}$$

$$x_{ijk} \in \{0,1\}, i = 1,2, \dots ,17, j = 1,2 \dots ,30, k = 1,2, \dots ,10 \tag{33}$$

Goals: Three goal constraints were determined to minimize the deviations in the 0-1 integer goal programming model.

Goal 1: The total working time of the medical staff in the laboratory department in the areas numbered 1-7 (working time in each area is 8 hours) should be as equal as possible. (There is no laboratory supervisor in this areas.)

$$8\sum_{j=1}^{30}\sum_{k=1}^{7} x_{ijk} + d_i^- - d_i^+ = 104, i = 1,2,\dots,16 \quad (34)$$

Goal 2: The total working time of the medical staff in the laboratory department should be as equal as possible in the 16-hour laboratory shift.

$$16\sum_{j=1}^{30} x_{ij8} + e_i^- - e_i^+ = 32, i = 1,2,\dots,17 \quad (35)$$

Goal 3: The total working time of the medical staff in the laboratory department should be as equal as possible in the 24-hour laboratory shift.

$$24\sum_{j=1}^{30} x_{ij9} + f_i^- - f_i^+ = 24, i = 1,2,\dots,17 \quad (36)$$

4.4. Solution of 0-1 Integer Goal Programming Model for Shift Scheduling Problem in Laboratory Department

The GAMS software was used to solve the 0-1 integer goal programming model set up for the optimal shift schedule of the medical staff in the laboratory department of the hospital in November 2022. As a result of solving the model coded in the GAMS program, the shift schedule was found to be optimal. Table 1 shows the shift schedule used by the hospital for the medical staff in the laboratory department in November 2022. Table 2 shows the optimal shift schedule found as a result of solving the model for the optimal shifts of medical staff in the laboratory department in November 2022.

The shifts in the laboratory department for Table 1 and Table 2 are: 1: blood gas-sample separation, 2: urine, 3: biochemistry, 4: hormone, 5: transfusion & sedimentation, 6: microbiology, 7: haemogram & coagulation, 8: 16-hour laboratory shift, 9: 24-hour laboratory shift, 10: laboratory supervisor shift. Shifts 1-7 and 10 last 8 hours on weekdays, shift 8 lasts 16 hours on weekdays, shift 9 lasts 24 hours on weekends.

Table 1. November 2022 Shift Schedule of the Laboratory Department

Days \ Medical Staff	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	6	6	4		4		Day off			3	5		7	2	3-8	1-8	10
2	6	6	4	2-8	4	5-8		1			5	3	7	3			10
3	6	6	4		4			2-8	1-8	3	5	3	7				10
4	6	6	4	1	4					3	5	3	7	2-8			10-8
5				9		9											
6									9	9							
7	6	6	4	1	4			5			5	3	Day off	7	3-8	2-8	10
8	6	6	4		4	2-8		5	7	3	5	3		1-8			10
9	6	6	4		4			5	2-8	3-8	5	3			7	1	10
10	6	6	4	2-8	4			5			5	3		7	3	1	10-8
11	6	6	4		4-8	2-8		5	7		5	3		3		1	
12															9	9	
13				9										9			
14	6	6	4		4	2			5-8	Day off	Day off	3	7		3-8	1	10
15	6	6	4	5-8	4	2						3	7	3		1	10-8
16	6	6	4		4	5-8		5	1			3	7	2-8	3		
17	6	6	4	1	4			5	2-8			3-8	7		3	5	10
18	6	6	4	2	4	3		5					7	1	3-8	5-8	10
19	9	9															
20				9		9											
21	6	6	4		4		2	5-8	1	3	5	3	7			7-8	10
22	6	6	4		4		2		1	3-8	5	3	7		5-8		10
23	6	6	4		4	1-8	2	7	3		5	3	7	5-8			10
24	6	6	4	7	4		2	3	1-8		5	3	7			5-8	10
25	6-8	6-8	4	5	4		2	1		3	5	3	7				10
26														9			9
27															9	9	
28	6	6	4	5-8	4	1-8	2	3		7	5	3	7				10
29	6	6	4		4		2	3-8	1	7-8	5	3	7		5		10
30	6	6	4		4		2		3		5	3	7	1-8	5		10-8
Total Number of Shifts in the Laboratory Department																	
Total Number of 8-Hour Shifts	**22**	**22**	**22**	**10**	**22**	**9**	**8**	**16**	**13**	**10**	**17**	**20**	**17**	**12**	**11**	**11**	**20**
Total Number of 16-Hour Shifts	**1**	**1**	**0**	**4**	**1**	**6**	**0**	**3**	**5**	**3**	**0**	**1**	**0**	**5**	**5**	**5**	**4**
Total Number of 24-Hour Shifts	**1**	**1**	**0**	**3**	**0**	**2**	**0**	**0**	**1**	**1**	**0**	**0**	**0**	**2**	**2**	**2**	**1**

Source: Obtained from the laboratory supervisor in the laboratory department of the applied hospit.

Table 2. Optimal Shift Schedule Proposed for the Laboratory Department for November 2022

Days \ Medical Staff	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	4-8	6	5	6		7	Day off				1-8	2	3	3		4	10
2			6	2	4-8	1		3	5-8			7	4	3	6		10
3		4	4	6-8		2				7	5		3	3	1	6-8	10
4		6-8			6	4		3	7	5-8	3	1	4	2			10
5	9															9	
6		9		9													
7	6		3		5	3-8		4-8		1	2	7	Day off		4	6	10
8	6		6-8	4	3				2	5	7	3		4-8	1		10
9	3	6		2	5			1	7-8	4		6-8			3	4	10
10	4	3	5-8	6		6		4		1	7			2	3-8		10
11	3	6		3	4	4-8		1-8			2	7		5		6	10
12			9						9								
13					9							9					
14		3	7	1-8		6		2	4	Day off	Day off		4	6	5	3-8	10
15	4	3	5		4			1	2			6	7-8	6	3		10-8
16	3	4	5	7	1-8	6		4	3						2-8	6	
17	3		6	1		3		4	2			6-8	4	5		7	10-8
18	3-8	6		5	7	3		4	1				4	2-8	6		
19							9			9							
20								9							9		
21			2	4	1	7	3-8			5-8		6	4	6		3	10
22	4	3-8	1		3				6		2-8	5		6	4	7	10
23	6		4-8		1	3	3		7	4		6	5-8		2		10
24		7		4		5-8	4	1	3		2	3		6-8		6	10
25	4-8		5	7	6		3	2	6	3					1-8	4	10
26						9					9						
27													9	9			
28	3	6			4-8		6	7	4-8	3	1	2				5	10
29	4	3	5	3-8		6	7	4				1-8			2	6	10
30		6-8			7		3-8		3	6	2		4	5	4	1	10
Total Number of Shifts in the Laboratory Department																	
Total Number of 8-Hour Shifts	**15**	**15**	**15**	**15**	**15**	**15**	**7**	**15**	**15**	**11**	**11**	**15**	**11**	**15**	**15**	**15**	**20**
Total Number of 16-Hour Shifts	**3**	**3**	**3**	**3**	**3**	**3**	**2**	**2**	**3**	**2**	**2**	**3**	**2**	**3**	**3**	**2**	**2**
Total Number of 24-Hour Shifts	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**0**

4.5. Evaluation of the Solution of 0-1 Integer Goal Programming Model for Shift Scheduling Problem in Laboratory Department

According to Table 1, it can be seen in Table 2 that the total working hours of the medical staff in the laboratory department in the 8-hour (excluding the 7th, 10th, 11th and 13th medical staff who took day off during the month), 16-hour and 24-hour shifts were distributed as evenly as possible. This ensured that table 2 represented an fair schedule for medical staff. Since the 17th medical staff is the responsible staff in the laboratory department, he/she must be present at the 8-hour laboratory supervisor shift every weekday (except the day after the 16 and 24 hour laboratory shifts). Therefore, the 17th medical staff was not included in the first goal, which was set to ensure that the total working time for 8-hour shifts was as equal as possible. Hence, in table 2, the 8-hour shift of these staff is higher than the 8-hour shift of other staff. In addition, in Table 2, in November 2022, the requirement for each staff member who does not take the day off to work at least 176 hours, for the 7th medical staff member who takes 18 days off to work at least 64 hours, for the 10th, 11th and 13th medical staff who take 5 days off to work at least 136 hours is also fulfilled. The number of medical staff required to be present in all shifts are provided in Table 2. Thus, the operation of the laboratory department was not disrupted. In addition, in Table 2 the legal conditions set by the hospital for the laboratory department are provided. If the optimal schedule in Table 2 is applied in the laboratory department, the productivity of the medical staff in this department will increase. The efficient work of the medical staff will increase the satisfaction of the patients and the hospital. As a result, the fairness and efficiency of the optimal schedule will positively affect the medical staff and ensure the correct use of the hospital's resources. In the future, optimal schedules can be obtained by building models similar to the model in this study for laboratory departments in hospitals and by adding different constraints related to hospital or medical staff to these models.

5. CONCLUSIONS

The health sector should work most accurately compared to other sectors. It is important to organize hospitals, which have the largest share in the health sector, in a planned manner. Personnel scheduling in hospitals is a complex scheduling problem with many constraints and multiple objectives. Because of these constraints and objectives, it is tiring and time-consuming for the staff who create these schedules to create schedules over and over again within a given period of time. Furthermore, it is difficult to manually create these schedules in a fair and efficient manner. However, by using mathematical methods in scheduling, optimal schedules can be generated in a short period of time. The obtained optimal schedules are not only fair and efficient for the staff, but also enable the hospital to use its resources efficiently.

In this study, the one-month shift schedule of medical staff in the laboratory department, one of the departments of the hospital, was optimally planned. For the study, the November 2022 shift schedule data in the laboratory department of a government hospital in Gümüşhane, the legal conditions of the hospital, and the functioning of the laboratory were used. Using this information and data, a 0-1 integer goal programming model was created to optimize the November 2022 shift schedule in the hospital's laboratory department. The model was coded and analyzed in GAMS 42.5.0. As a result of the analysis of the model, the shift schedule for the laboratory department of the hospital for November 2022 was obtained optimally. Comparing Table 1, the shift schedule used by the hospital in November 2022, with Table 2, the optimal schedule, Table 2 has the total work hours of the medical staff in the laboratory department distributed as evenly as possible in 8-hour, 16-hour, and 24-hour shifts. In table 2, the number of staff required to ensure that the operation of the laboratory department is not interrupted during shifts is provided. If the hospital applies the optimal schedule in Table 2 for the laboratory department, the medical staff in that department will be assigned to their shifts with fair and efficient schedule. This will increase the satisfaction of the medical staff, the hospital, and the patients. In addition, this schedule will lead to cost minimization for the hospital because the hospital's resources will be used properly. In this study, it is shown that shift schedule can be optimized and resources can be used correctly with the 0-1 integer goal programming model established for the laboratory departments of hospitals.

It is thought that the model in this study will serve as an example in establishing efficient and fair shift schedule for the hospital and medical staff by establishing similar models in future shift scheduling in laboratory departments of hospitals. Similarly, this study can be used in goal programming models established for different departments of the hospital according to constraints such as the working conditions of the hospital and the department, shift scheduling of the staff, especially day off, preferences, and so on. In future studies, in addition to goal programming, heuristic methods, genetic algorithms, decision support systems, and simulations can be used to solve complex problems that arise when the number of decision variables, constraints, and goals increases. Apart from these methods, AHP, ANP or multi-criteria decision making methods can be used to determine the objectives in goal programming. Furthermore, in future studies, GAMS software or other programs can be used to solve goal programming models.

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