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Research Article

GOAL PROGRAMMING APPROACH FOR THE RADIOLOGY TECHNICIAN SCHEDULING PROBLEM

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ABSTRACT

Population growth is led to an increase in demand in the health sector. Health services need to be met at the maximum level in the face of increasing demand. The number of patients per each health personnel in Turkey is too much. Considering this situation, it is seen that ensuring patient satisfaction is directly proportional to the satisfaction of the personnel. For this reason, some studies such as the positioning of polyclinics and hospitals encountered in health services, capacity planning and demand estimations, as well as the studies about the creation of study schedules of health personnel are also gained importance. In this study, it is aimed to provide the personnel satisfaction as much as possible. The Law No. 3153 on Radiology, Radionomy and Electrical Therapy and Other Physiotherapy Institutions published by the Ministry of Health of the Republic of Turkey, dated 19/4/1937, as well as the requirements of the Annex-1 of 21/1/2010, is considered. The scheduling problem for eight radiology technicians working in a private hospital in Ankara is discussed. A mathematical model is proposed using the goal programming method in order to assign the technicians to the four shifts as equally as possible. According to the researches, this is the first study which has the feature of radiology technicians and by considering government and hospital conditions as well as with staff requests, by application area.
Keywords: Radiology technician, scheduling, goal programming.

1. INTRODUCTION

Hospitals are 24-hour service providers and therefore are working with shift system. A shift system is a system that is difficult to manage because it depends on the attention, motivation and efficiency of the health personnel providing this service [1]. For this reason, it is very important to make health management more effective and provide patient satisfaction in the organizations providing this service. The number of patients per each health personnel in Turkey [2,3] is considered, it is seen that patient satisfaction is directly proportional to the satisfaction of the personnel. At this point, it is seen that planning studies have great importance. In order to ensure

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the highest level of service quality, it is important to increase the satisfaction of personnel in these plans [4]. For this purpose, in the literature, optimization problems in healthcare planning, resource planning and health care services are included in the literature for more than thirty years. The problems of personnel scheduling from these problems are frequently studied in the literature [5-6]. These studies, especially Gür and Eren [4], Rais and Viana [5], Batur and Erol [6] are presented studies from a wide perspective in their literature reviews. Rais and Viana [5], which included studies based on operations research in the health sector, is presented the studies by classifying them according to the problem types. Batur and Erol [6]' study are based on the current studies on this issue between 2007-2017. They have categorized the studies under three main headings and presented the problem type, the methods used, and whether they were applied in real life or not. Gür and Eren [4], who carried out a detailed review of the goal programming-based scheduling and planning studies in service systems, are classified the studies under three different headings: scheduli ng and planning types, goal programming types and integrated methods. Personnel scheduling, which is one of the subheadings [7] on service system scheduling, is one of the subjects frequently studied in the literature in recent years in line with the objectives of the employees and service areas and the purpose of distributing the workload required to the personnel as equally and equally as possible based on the enterprise's policies. There are many objectives to be performed in service systems and there are many factors that affect these objectives. While some of the objectives may conflict with each other, some may be proportional to each other. Effective schedules are required to be able to fulfil these objectives simultaneously and to deliver each defined task on time. These schedules in service systems vary in the health sector, including operating rooms, polyclinics, surgeons, and nurses [7]. Bradley [9]; Ernst [10]; Brucker [11]; Van den Bergh [12]'s studies are also shown that many scheduling problems have occurred in the field of personnel scheduling. When the personnel scheduling studies in health systems are examined, it is aimed to increase the service quality. Although the problems discussed are different according to their application areas, it is desired to have balanced charts and to increase personnel satisfaction. The continuity of uninterrupted service in the health sector that provide service 24/7 emphasizes the importance of the schedules. Personnel scheduling problem, which provides a positive effect on personnel performance in terms of increasing the motivation of employees by producing a fair and balanced work plan; different methods such as integer programming [22], neighbouring search [23] [21], including goal programming [21] in various fields such as transport [14-18], military [8], [19] and energy [13], [20] have applied. In the field of health, especially doctors [24-26], operating room [21], [27-28] and performance scheduling [22], [29] problems and more nursing scheduling [30-32] problems are included. Regarding the problem of the scheduling of radiology technicians, which are the subject of this study, no studies are found according to the investigations. Therefore, models of nursing scheduling problems, which are frequently studied in this area, are examined in the modelling phase of the problem. [33-36] are described the solution approaches for the assignment problems of nurses in hospitals. First, they have examined the studies in the literature and then they are pointed out the role played by nurses in their planning for a longer period. They are described and critically evaluated the solution approaches in the interdisciplinary spectrum from operational research techniques to artificial intelligence methods. As the number of factors affecting the problem increases, the complexity of the problem increases and the ratio of the problem to reach the goals decreases. For this purpose, the researchers model the objectives as a multi-purpose optimization problem. Burke et al. [23], Tsai and Lee [37], Topaloglu and Selim [38]'s studies can be shown as an example. Researchers who prefer the goal programming method studies which enable these purposes to be realized simultaneously are found in the literature. Some studies addressing the nurse scheduling problem [3], [30-31], [40-42] are benefited from the flexibility of the goal programming method [4]. For these purposes, which are likely to conflict with each other, decision-makers are able to achieve effective results from the solution of problems. Individual preferences of nurses were taken into consideration in the studies. In this way, the satisfaction of the personnel was also asked to be brought to the top level. In this study, the scheduling problem for eight radiology technicians working in a private hospital in Ankara and working with four shifts is discussed. Considering the Law on Radiology, Radionomy and Electrical Therapy and Other Physiotherapy Institutions published by Ministry of Health of the Republic of Turkey dated 19/4/ 1937 and numbered 3153, the requirements of the Annex-1 of 21/1/2010 as well as personnel requests, a mathematical model with goal programming was proposed. Unlike working conditions for other staff in the hospital, radiology technicians are exposed to radiation extensively. Therefore, it is necessary to provide special conditions such as a maximum of 7 hours per day for a total of 35 hours per week and a continuous leave of one month per year [2]. For this reason, the study conducted is the first in the literature with the limitations of the place of application as well as the constraints of government and hospital as well as meeting the demands of the personnel.

This study consists of four parts. In the second part of the study, the goal programming method, the third part of the problem definition and finally the fourth part of the study results are given.

2. GOAL PROGRAMMING METHOD

In decision problems, it is not always possible to choose the most suitable one among many options. While some of the objectives may conflict with each other, some may be proportional to each other. In some cases, too many factors need to be ignored in order to obtain an optimal solution. There are multi-criteria decision-making methods developed to evaluate multiple criteria that are effective on the problem at the same time. The goal programming method, which is among the multi-criteria decision-making methods, is a tool that helps to find solutions in complex problems. It was first described by Charnes and Cooper in 1961. Flexibility is allowed in the solution process with the goal programming method. In other words, it is possible to reach the desired goals at the same time by allowing deviations through goal constraints [4].

Planning and scheduling systems can be faced with many different problems. Scheduling and planning activities in service systems have applications in many areas [7]. It is used goal programming method in the shift scheduling [8], cleaning personnel scheduling [43], menu planning [44-46], security personnel scheduling [47], examiner scheduling [48], transport planning [49]. Increasing the quality of service provided to customers in service systems is one of the priorities aims. In such decision problems, decision makers want to achieve their goals as much as possible. In the literature, the goal programming types frequently used by researchers are weighted and priority goal programming.

2.1. Weighted goal programming method

The common feature of mathematical modeling is that they have a single objective function. In the goal programming method, modeling simplicity is provided to achieve multiple objectives at the same time. With the help of weighted goal programming, decision-makers can rank importance among their objectives. Weight can be assigned to the purpose that he thinks is more important than the other. At the same time, penalty function is provided to researchers by weighting. With this penalty coefficient, decision makers can be modeled in such a way as to minimize the aim that needs to be considered and reduced. These weights can be determined as a result of the managerial analysis of the current situation or by the support of analytical methods. When the literature on weighted goal programming is examined, it is seen that decision makers weight on goals in decision-making processes. In the studies, the goal programming method is used by integrating with different analytical methods, as well as being used alone [35]; [38]; [40]; [50-58].

In the weighted goal programming method, according to the characteristics of the problems, the decision makers define a specific weight on the goals. In the solution phase of the model, the objective function minimizes the weighted sum of these deviations. The mathematical representation of the weighted goal programming is as follows [59-60];

$$Min_z = \sum_i^k (\alpha_i \, d_i^- + \beta_i d_i^+) \tag{1}$$

s.t.

$$f_i(x) + d_i^- - d_i^+ = b_i \,, \quad i = 1 \dots Q \,, \; x \in C_s \tag{2}$$

Expressions in the given mathematical model; $f_i(x)$ represents a linear function of x, the attainment of b_i represents the desired goal value, d_i^- , d_i^+ represents the deviation values in the negative and positive directions from the goal values, C_s represents a set of constraints in linear programming. $\alpha_i = w_i/k_i$ if d_i^- is unwanted, otherwise $\alpha_i = 0$ and $\beta_i = w_i/k_i$ if d_i^+ is unwanted, otherwise $\beta_i = 0$. The parameters w_i and k_i are the weights reflecting preferential and normalizing purposes attached to the achievement of the ith goal.

3. A CASE STUDY

In this study, considering the study rules of radiology technicians in a hospital in Ankara and the Law on Radiology, Radiology and Electrotherapy and other Physiotherapy Institutions dated 19/4/1937 and published by the Ministry of Health of the Republic of Turkey, a mathematical model is proposed in order to be assigned to the shifts determined in line with the requirements of the Annex-1. Goal programming method was used for the model. Problem solving IBM ILOG CPLEX [61] In the Optimization Studio, the Intel ® Core ™ i3 CPU is performed on a computer with a 2.40 GHz processor in 5.7 seconds. There are 4704 variables in the model solution.

Problem definition

There are four shifts in the 24-hour hospital. The first shift is between 08: 00-15: 00, the second shift is 11: 00-18: 00, the third shift is between 18: 00-01: 00 and the fourth shift is between 01: 00-08: 00. A technician is at ray permit and 8 technicians are working in this month. The model structure of the problem, including the constraints and objectives to be provided, is as follows:

Parameters:

j: Day index	j=1,...,l	l=28
k: Shift index	k=1,…,m	m=4
i: Technician index	i=1,...,n	n=8

Decision Variables

$$X_{\boldsymbol{ijk}} = \begin{cases} 1, & \text{if i technician to j day to k shift is assigned} \\ 0, & otherwise \end{cases} \tag{3}$$

$$\mathrm{i} = 1,\ldots,\mathrm{n} \quad \mathrm{j} = 1,\ldots,\mathrm{l} \quad \mathrm{k} = 1,\ldots,\mathrm{m}$$

$$\mathrm{H_{ij}} = \begin{Bmatrix} 1, \text{if i technician to j day is not work} \\ 0, \qquad\qquad\qquad \text{otherwise} \end{Bmatrix} \mathrm{i} = 1,\ldots,\mathrm{n} \quad \mathrm{j} = 1,\ldots,\mathrm{l} \tag{4}$$

Mathematical Model

$$Min \sum_{i=1}^{n} \sum_{j=1}^{l} \sum_{k=1}^{m} (d_1^+ + d_1^- + d_2^+ + d_2^-) \tag{5}$$

$$\sum_{i=1}^{n} X_{ij1} \geq 2 \qquad j = 1,\ldots,l \tag{6}$$

$$\sum_{i=1}^{n} \sum_{k=2}^{m} X_{ijk} \geq 1 \qquad j = 1,\ldots,l \tag{7}$$

$$\sum_{i=1}^{n} \sum_{k=2}^{m} X_{ijk} \leq 2 \qquad j = 1,\ldots,l \tag{8}$$

$$\sum_{k=1}^{m} X_{ijk} \leq 1 \qquad i = 1,\ldots,n \quad j = 1,\ldots,l \tag{9}$$

$$\sum_{k=1}^{m} X_{ijk} + H_{ij} = 1 \qquad i = 1,\ldots,n \qquad j = 1,\ldots,l \tag{10}$$

$$H_{ij} + H_{i(j+1)} + H_{i(j+2)} + H_{i(j+3)} + H_{i(j+4)} + H_{i(j+5)} + H_{i(j+6)} \geq 2 \qquad i = 1,\ldots,n \quad j = 1,\ldots,l-6 \tag{11}$$

$$X_{ij4} + X_{i(j+1)1} \leq 1 \qquad i = 1,\ldots,n \qquad j = 1,\ldots,l-1 \tag{12}$$

$$X_{ij4} + X_{i(j+1)2} \leq 1 \qquad i = 1,\ldots,n \qquad j = 1,\ldots,l-1 \tag{13}$$

$$X_{ij4} + X_{i(j+1)3} \leq 1 \qquad i = 1,\ldots,n \qquad j = 1,\ldots,l-1 \tag{14}$$

$$X_{ij3} + X_{i(j+1)1} \leq 1 \qquad i = 1,\ldots,n \qquad j = 1,\ldots,l-1 \tag{15}$$

$$X_{ij3} + X_{i(j+1)2} \leq 1 \qquad i = 1,\ldots,n \qquad j = 1,\ldots,l-1 \tag{16}$$

$$X_{ij2} + X_{i(j+1)2} + X_{i(j+2)2} \leq 2 \qquad i = 1,\ldots,n \qquad j = 1,\ldots,l-2 \tag{17}$$

$$X_{ij3} + X_{i(j+1)3} + X_{i(j+2)3} \leq 2 \qquad i = 1,\ldots,n \qquad j = 1,\ldots,l-2 \tag{18}$$

$$X_{ij4} + X_{i(j+1)4} + X_{i(j+2)4} \leq 2 \qquad i = 1,\ldots,n \qquad j = 1,\ldots,l-2 \tag{19}$$

$$\sum_{j=1}^{l} \sum_{k=1}^{m} X_{ijk} + d_1^- - d_1^+ = 20 \qquad i = 1,\ldots,n \tag{20}$$

$$\sum_{j=1}^{l} X_{ijk} - X_{(i+1)jk} + d_2^- - d_2^+ = 0 \qquad i = 1,\ldots,n-1 \quad k = 1,\ldots,m \tag{21}$$

In the proposed model, it refers to the objective function that specifies the minimization of the deviation in the goals to be achieved in Equation 5. The constraints that reflect the capacities of the technicians specified by the hospital are in Equation 6-Equation 8. Equation 6 from these constraints refers to the number of technicians who are required to work in the first shift, while Equation 7 and Equation 8 represent the number of technicians required to work in the second, third and fourth shifts. In addition to these constraints, a technician can work only one shift per day in Equation 9. In addition to these constraints, a technician can work only one shift per day in Equation 9 and is not working when it is allowed in Equation 10. According to the regulation issued by the Ministry of Health of the Republic of Turkey [2], there is a limitation that radiology technicians should work for a maximum of 35 hours per week, 7 hours per day in Equation 11. In the model, the constraints from Equation 12 to Equation 19 reflect the constraints created by taking into consideration the desire of radiology technicians working in the hospital. Equation 12 and Equation 14 show the assigned of the technician working in the fourth shift the next day on the first, second and third shifts. Equation 15 and Equation 16 are the constraints that allow the technician working in the third shift to not be assigned to the first and second shift the next day. In addition, the constraints between Equation 17 and Equation 19 show that technicians should work for a maximum of two days in succession on second, third and fourth shifts. It is also the constraints that the personnel are always prevented from being assigned to the same shift. Finally, Equation 20 and Equation 21 are the goals to be provided in the model. Equation 20 indicates that each technician should work in a maximum of 20 shifts for a month. Equation 21 indicates that each technician should be assigned an equal number of shifts each month at the end of a month. Table 1 shows the table obtained as a result of the model. According to the obtained results, the goals are reached with a little deviation. In the schedule, the regulation published by the Ministry of Health of the Republic of Turkey [2] and the requirements of the hospital management and staff are met.

Table 1. The schedule which is obtained as a model result

	DAYS																												TOTAL ASSIGNMENTS					
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	S1	S2	S3	S4	H	T
1	S1	S2	S3		S1	S2		S2		S1	S1		S3	S3		S1	S3	S4		S4	S4		S1	S4	S4		S2	S1	7	4	4	5	8	20
2	S2	S4		S1	S4		S2		S1	S3		S2	S1	S4		S1	S4		S1	S3	S3		S1		S1	S2	S3	S4	7	4	4	5	8	20
3	S2	S1	S1	S3			S1	S3	S4		S4		S2	S1	S2	S3		S4		S1	S1	S4		S2	S4		S1	S3	7	4	4	5	8	20
4			S1	S2	S3	S3	S4			S1	S1	S1	S4	S4			S2	S3	S3	S4	S4			S1	S2	S1	S1	S2	7	4	4	5	8	20
5	S4		S2		S1	S1	S3	S4		S3		S1	S1	S2	S4		S1		S2	S2	S1	S1		S3		S3	S4	S4	7	4	4	5	8	20
6	S3	S3	S4	S4		S4		S1	S1	S2	S3		S4		S1	S2	S1	S1		S1		S2	S2	S1	S3		S4		7	4	4	5	8	20
7	S1	S1	S4		S3		S1	S2	S2	S4		S4		S1	S3	S4		S2	S4		S2	S3	S3		S1	S1		S1	7	4	4	5	8	20
8	S4	S4		S1	S2	S1		S3		S2	S3	S3		S1	S4		S1	S1	S1	S2		S1	S4		S3	S4		S2	7	4	4	5	8	20

H: Holidays, T: Total shift

Table 2. Scenarios created under different situations and solution results

Scenario	Personal number	Number of staff in 1st shift	Number of staff in 2st shift	Number of staff in 3st shift	Number of staff in 4st shift	Deviation
1	12	>=3	2, 3	2,3	1,2	0
2	16	>=3	3,4	4	1	2
3	19	6	2,3,4,5	3,4,5	1,2	2
4	23	>=7	4,5,6,7	3,4,5,6,7	1,2	0

4. CONCLUSION AND DISCUSSION

In this study, the problem of establishing a fair and balanced personnel schedule for eight radiology technicians in which the requirements of hospital management and the regulation published by the Ministry of Health of the Republic of Turkey [2]. Personnel scheduling problem, which provides a positive effect on personnel performance in terms of increasing the motivation of employees by producing a fair and balanced work plan [13], have many different areas such as transport [14-18], military [8], [19] and energy [20] with using different methods. In the field of health, especially doctors [24-26], operating room [21], [27-28] and performance scheduling [22], [29] problems and more nursing scheduling [30-32] problems are included. However, as far as the literature is concerned, no study has been found on the problem of scheduling radiology technicians, which is the subject of this problem. Therefore, this problem is the first in the literature as it is examined by considering the special constraints that exist for both the field of application and radiology technicians. As a result of the proposed mathematical model, the desired goals are reached.

Looking at the real-life system operation for the problem discussed, it is seen that the tables are prepared manually by a single person. This leads to an unfair distribution of personnel. As a result, the performance of the personnel is affected. As a result of personnel satisfaction provided by the proposed model, patient satisfaction has been increased. In addition, the equal distribution of personnel across shifts equals the amount of radiation exposed due to the varying demand on different shifts. It is expected that the staff will work more efficiently as a result of achieving a fair and healthier work environment. Looking at the literature, this study distinguishes personnel scheduling problems with special limitations in its structure. Nursing scheduling problem mostly focuses on health personnel scheduling [35]; [40-42]; [62-63]. This study, on the other hand, is expected to come to the forefront in the literature due to its application area, its specific limitations, its solution method and its ability to be a different subject for researchers in the future. As stated in the study by Gür and Eren [4], the goal programming approach enables decision makers to realize the goals simultaneously in service scheduling problems. At this point, due to the nature of this problem, it is necessary to formulate schedules carefully in order to ensure a balanced distribution of the workload and to prevent workers from being affected by radiation. The goal programming method also helps to achieve these objectives of the study. The goal programming method also helps to achieve these objectives of the study. In nursing scheduling problems that are specialized in the field of health, the aim of ensuring patient satisfaction is also prioritized. Shift systems that differentiate and specialize in health systems provide patient satisfaction, while shift loads need to be paid attention in order to ensure a high level of performance from staff [31];[40]. The application addresses radiology technicians differently from normal nurse scheduling problems. In the radiology technician scheduling problem, there is a radiation environment in which technicians are exposed for a long time. As this situation affects the health status of the personnel negatively, working conditions and work plans are prepared by taking this situation into consideration. This difference not only aims to work equally among staff, but also to work equally in shifts to equalize the amount of radiation received. It is also important to keep the personnel' ability to take X-ray images correctly and to pay attention to details. Excessive workload on personnel allows negligence to occur at these points. In addition, long-term standing is also an impressive aspect of personnel performance. When all these points are considered, radiology technician makes scheduling problem an important and special position among health service scheduling problems. At this point, this study, which is distinguished from other studies in the literature, has created a schedule that considers the health conditions as well as a fair and balanced workload for radiology technicians. In this way, it was requested to prevent the negativities experienced in these schedules prepared previously for the personnel. At the same time, different scenarios have been tried in the study and schedules have been prepared for possible situations. Deviations from the obtained results are given and the effectiveness of the model is shown. Deviations from the obtained results are given and the effectiveness of the model is shown. Looking at the literature for a longer schedule with current permits, it was found that annual shift scheduling was not performed. When the studies in the literature are examined, 1-month schedules have been created in shift scheduling studies, usually because of their ease of application and effectiveness in real life. For this reason, this study was carried out again for 28 days and 1 of 9 technicians was solved with the assumption that they were in the permission and 1 month shifts were scheduled for the remaining 8 technicians. Instead of the annual plan, scenarios were created by taking into account the different number of personnel and the differentiation of the demand in shifts. Scenarios and table with deviations are added. The reason for the deviation is that the number of technicians required in shifts is defined by a clear number instead of being defined by an interval, ie when defined as a hard constraint.

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