ACTA INFOLOGICA 2023;7(1):81-93
dergipark.org.tr/acin

DOI: 10.26650/acin.1096774

RESEARCH ARTICLE

Application of Integer Response Optimization Models for the Healthcare Resources

Sağlık Kaynakları için Tam Sayılı Yanıt Optimizasyon Modellerinin Uygulanması

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Submitted: 31.03.2022
Revision Requested: 12.12.2022
Last Revision Received: 15.03.2023
Accepted: 14.03.2023
Published Online: 07.04.2023

Citation: Atalan, A. (2023). Application of integer response optimization models for the healthcare resources. *Acta Infologica, 7*(1), 81-93. https://doi.org/10.26650/acin.1096774

ABSTRACT

This study investigated the relationship between the number of hospitals and healthcare professionals in the Turkish healthcare system. The study data covers the years 1967-2018. In the study, statistical analysis was performed, and the integer response optimization models were created using the linear regression response optimization models. The Pearson correlation test was applied to show the relationship between decision variables. The percentage of variation of the response variable specified by the linear regression model was calculated as 97.85. The numbers of nurses (p value=0.001, f value=21.36, t value=-4.62), midwives (p value=0.001, f value=24.88, t value=4.99), and OHP (Other health professionals) (p value=0.001, f value=24.16, t value=4.92) were found to be effective on the number of hospitals, doctors and pharmacists were not effective on the number of hospitals with a margin of error of 1.00% or 5.00%. The optimum number of healthcare workers required to provide health services in 1798 hospitals was calculated as 153128 doctors, 165244 nurses, 56351 midwives, 32032 pharmacists, and 177409 OHP. As a result of this study, we confirmed that the Turkish government should be able to provide health services in more hospitals with the existing healthcare system resources.

Keywords: Turkish healthcare system, healthcare professionals, hospitals, integer response optimization models

ÖZ

Bu çalışma, Türk sağlık sistemindeki hastane sayısı ile sağlık profesyonelleri arasındaki ilişkiyi araştırmak amacıyla yapılmıştır. Çalışma verileri 1967-2018 yıllarını kapsamaktadır. Çalışmada istatistiksel analizler yapılmış ve lineer regresyon yanıt optimizasyon modelleri kullanılarak tamsayılı yanıt optimizasyon modelleri oluşturulmuştur. Karar değişkenleri arasındaki ilişkiyi göstermek için Pearson korelasyon testi uygulanmıştır. Doğrusal regresyon modeli ile belirlenen yanıt değişkeninin varyasyon yüzdesi 97,85 olarak hesaplanmıştır. Hemşire (p değeri=0,001, f değeri=21,36, t değeri=-4,62), ebe (p değeri=0,001, f değeri=24,88, t değeri=4,99) ve diğer sağlık çalışanları (DSÇ) (p değeri=0,001, f değeri = 24.16, t değeri=4.92) hastane sayısı üzerinde etkili bulunmuş, doktor ve eczacı hastane sayısı üzerinde %1.00 veya %5.00 hata payı ile etkili olmamıştır. 1798 hastanede sağlık hizmeti vermek için gereken optimum sağlık çalışanı sayısı 153128 doktor, 165244 hemşire, 56351 ebe, 32032 eczacı ve 177409 DSÇ olarak hesaplanmıştır. Bu çalışmanın sonucunda, Türk hükümetinin sağlık sisteminin mevcut kaynakları ile daha fazla hastanede sağlık hizmeti sunabilmesi gerektiği doğrulanmıştır.

Anahtar Kelimeler: Türk sağlık sistemi, sağlık profesyonelleri, hastaneler, tamsayılı yanıt optimizasyon modelleri

1. INTRODUCTION

The healthcare systems of countries consist of two cornerstones: the human factor and physical structures. The main point is the human factor rather than the physical structures when health systems components are examined in detail (Leonard 2004; Taylor 1976). The human factor, health workers such as doctors, nurses, technicians, assistants, etc., is at the center of health services (Khatri et al. 2006). Healthcare system sections are divided into employees and organizations (Atalan and Donmez 2020; Mihaylova et al. 2011). While employees create the human factor, doctors, midwives, nurses, technicians, etc., structures such as hospitals, clinics, etc., are classified as healthcare institutions. Some researchers have handled these classifications as healthcare components and health resources (Siciliani, Stanciole, and Jacobs 2009). For example, while hospitals, private health insurance companies, patients, and rule-making states are considered health components, doctors, nurses, number of beds, etc., are defined as healthcare resources (Lovink et al. 2017; Shinjo and Aramaki 2012).

The components or resources that researchers define make up health systems as variables, factors, elements, etc. (Maleki, Majlesinasab, and Sepehri 2014; Mihaylova et al. 2011). These dependent and independent variables affect the dependent variable (Ahmed and Alkhamis 2009; Thapa et al. 2018). In this study, five independent variables and one dependent variable were considered. While the number of hospitals was defined as the dependent variable, four independent variables were determined as the number of doctors, nurses, midwives, pharmacists, and other healthcare workers. Researchers have used many methods to reveal the link between dependent and independent variables (Atalan 2021; ATALAN 2020). Since healthcare systems have complex and dynamic structures, a single process is insufficient to solve the problem (Ramudhin, Chan, and Mokadem 2006). For this reason, many methods specific to healthcare problems are used at the same time. Statistical analysis approaches are used at the beginning of an examination of healthcare problems (Dönmez, Atalan, and Dönmez 2020; Malehi, Pourmotahari, and Angali 2015; Pellegrini, Rodriguez-Monguio, and Qian 2014). Also, the correlation values between dependent and independent variables defined in this study were computed using the linear regression analysis method. In addition to the correlation values of the health resources considered for health management, the correlation values were calculated indicating the types of diseases seen which are useful in health resource planning (Cheng et al. 2022). However, in this study, data on disease types were not considered in health resource management.

This study examined the health resources affecting Turkey's healthcare economy using linear regression statistical analysis. Using the data for the years 1990-2016, per capita income, and population showed that the number of doctors was statistically significant, while the number of nurses and beds was insignificant (Atalan 2018). This study did not use the healthcare economy and population of Turkey data. Kan et al. estimated future healthcare costs for the elderly and compared the results obtained from using two methods, standard and linear regression (Kan et al. 2019). Data from 2,911 patients were analyzed using 'chi-square tests, one-way ANOVA, multiple linear regression, and binominal logistic regression to determine statistically whether outpatients received medical attention from the same physicians (Lee, Chang, and Du 2017). Another study used the linear regression method to examine patient safety in a regional hospital, considering doctor and nurse variables. As a result, the effect of doctors and nurses on hospital safety culture was statistically emphasized in this study (Chi et al. 2017). Comparisons were made between these three occupations by measuring job satisfaction among doctors, nurses, and assistants with a linear regression model (Krogstad et al. 2006). Krogstad has preferred predictive logistic regression models to examine the perception of cooperation between 551 doctors and 2,050 nurses (Krogstad 2004). Researchers used a multiple logistic regression method to examine doctors' attitudes toward new nursing practices by expanding nurses' job descriptions (Brodsky and Van Dijk 2008). Regression analysis and one-sample t-test were used to characterize nurses' organizational commitment and job qualifications according to different dimensions in another study (Gabrani et al. 2016). Ishikawa used logistic regression analysis to estimate relevant factors resulting from the geographic distribution of physicians according to health policies (Ishikawa 2020). Regression analysis models have been widely used to solve many problems in the field of healthcare (Atalan 2014). The mathematical optimization models were developed as a second method to calculate this study's optimum healthcare component and resources.

Researchers in studies generally use optimization models in the field of healthcare to determine the number of healthcare resources, organize the shift system of healthcare resources, and eliminate unnecessary steps in the patient flow diagram

(Abdalkareem et al. 2021; Daldoul et al. 2018; Goienetxea Uriarte et al. 2017; Lin 2008). The optimization models contributed to an increase in the number of patients treated, a decrease in patient waiting times, and an increase in the efficiency of hospital resources (Atalan and Dönmez 2020; Daldoul et al. 2018; Schmid 2012). Optimization models such as linear, nonlinear, integer, dynamic, and static differ according to the problem addressed in healthcare (Agarana and Olokunde 2015; Batun and Begen 2013; Cabrera et al. 2012; Özcan and Tüysüz 2018; Steiner et al. 2015). This study used a linear optimization model since there was no interaction between independent variables.

As a result of optimizing the number of healthcare resources employed in emergency services using the discrete event simulation model with linear optimization, the patient waiting time was reduced, and the number of patients treated increased (Ahmed and Alkhamis 2009; Atalan 2022). In another study, optimum healthcare resource numbers were calculated to provide better healthcare by optimizing patient flow (Ansari et al. 2020). Ramudhin et al. developed a medBPM (medical Business Process Modeling) optimization model for the treatment process to examine patient flow movements, decision points, and waiting for queues in the healthcare system (Ramudhin et al. 2006). To efficiently plan the healthcare resources required for the operating rooms, a dynamically structured optimization model has been developed for healthcare institutions with limited healthcare resources, using the assignment problem method, one of the optimization types (Zhao and Wen 2021). It has been improved by multi-objective optimization models to regulate nurses' shift systems, which are essential in increasing healthcare service quality, reducing hospital budget, and improving staff work satisfaction (Chiang et al. 2019). The optimization models created for this study have two objective functions. The objective functions of the optimization models developed were not evaluated within the scope of the multi-objective optimization model, and the models were run separately.

This study consists of four parts. Literature information about the methods used for dependent and independent variables affecting healthcare systems are given in the first section. The data used in this study and the applied linear regression response optimization model method are provided in the second part. The statistical and optimization results obtained in the study are evaluated in the third part. The results and suggestions for future studies are stated in the conclusion.

2. DATA AND METHODOLOGY

The methodology part of this study consists of three parts. The study data and variables are given in the first part. Two methods were used in the study. The effect of independent variables on the dependent variable was statistically measured using linear regression analysis. The optimum results of dependent and independent variables were obtained by considering two different optimization models in the second method. Developed optimization models were created according to linear mathematical modeling since there is no interaction between the input variables.

2.1. Data and Variables

The study data belongs to the Turkish Healthcare System, and the data between 1967-2018 were obtained from the Turkish Statistical Institution (TUIK 2021). The data set was considered dependent (the number of hospitals) and independent (medical doctors, nurses, midwives, pharmacists, and other healthcare professionals), including six variables. Descriptive statistical data of these variables are shown in Table 1.

Table 1
Descriptive Statistics Data of Healthcare Resources

Variables Parameters	Medical Doctors	Nurses	Midwives	Pharmacists	Other Healthcare Professionals[1]	Hospitals
Types	independent	independent	independent	independent	independent	dependent
Notation	X_d	X_n	X_m	X_p	X_o	Y_{it}
Sample Size	52.00000	52.00000	52.0000	52.000	52.0000	52.00
Mean	67418.00	62160.00	31995.0	6686.0	48178.0	1024.9
Mean of Std. Dev.	6118.000	6584.000	2161.00	1150.00	6514.0	40.90
Std. Dev.	44114.00	47474.00	15587.0	8295.0	46974.0	294.70
Variance	19460413	22538122	242945	68814	220659	86866.1
Variance Coeff.	65.43000	76.37000	48.7200	49.720	97.500	28.760

Minimum	11875.00	6161.000	5621.00	2203	5997.00	646.00
Q_1	26534.00	24568.00	16949.0	11369	11846.0	776.30
Median	59018.00	52362.00	35680.0	17145	26468.0	945.00
Q_3	103570.0	81515.00	44248.0	23044	66144.0	1213.50
Maximum	153128.0	190499.00	56351.0	32032	177409.0	1534.0
Skewness	0.45.000	0.920000	-0.0600	-0.220	1.260000	0.4800
Kurtosis	-1.14.00	0.060000	-1.4900	-1.050	0.47000	-1.200

[1]Technicians, Biologists, ‘ Physiotherapists, Technicians, Technologists, Secretaries, etc. For detailed information: (TUIK 2021); Abbreviations: Coeff., coefficient; Std. Dev., standard deviation; Q_1, the first quartile of data; Q_3, the third quartile of data

The number of physicians among the independent variables is one of the cornerstones of healthcare systems. The number of doctors increased over the years, with a maximum of 153,128 doctors employed. The lowest level was in 1967 when 11,875 doctors were employed. An average of 64,417 physicians was employed during the years for which the data were taken into account. While a maximum of 190,499 nurses were employed in 2018, only 6,161 nurses were employed in 1967. The average number of nurses between these years was 62,160. Five thousand six hundred twenty-one midwives were employed in 1967, while a maximum of 56,351 midwives were employed in 2018. The average number of midwives between these years isapproximately 32,000.

Pharmacists play an essential role in the health system. The number of pharmacists employed in hospitals is deficient when compared with the number of pharmacists operating outside the hospital. This study considered the number of pharmacists working inside and outside the hospital. This study evaluated the number of pharmacists factor as an independent variable. While a maximum of 32,032 pharmacists worked in 2018, only 2,203 pharmacists worked in 1967. The average number of pharmacists between these years wasas 16,686. The average number of other health professionals (OHP) considered between these years was estimated as 48,178. While a maximum of 177,409 other health workers were employed in 2018, only 5,997 other health workers were employed in 1967. The average number of hospitals considered between these years was approximately 1,025. A maximum of 1,534 hospitals provided healthcare services in 2018, but only 646 hospitals provided services in 1981.

The number of hospitals fluctuated over the years. While an increase was observed from 1967 to 1980, the number of hospitals providing healthcare services decreased dramatically in 1981 and 1982. Although there was an increase in the number of hospitals from 1982 to 2001, there was a slight decrease until 2008. Although there was an increase in the number of hospitals providing health services from 2009 to 2014, there was a stagnation in the number of hospitals until 2018; even though there were fluctuations in the number of hospitals, the employment of healthcare personnel increased over the years. This study statistically analyzed whether healthcare personnel was affected by the fluctuations in the number of hospitals.

The correlation data of dependent and independent variables are given in Correlation values are measured according to the values between -1.00 and +1.00 between two variables. As the correlation values get closer to -1.00, they create a strong negative correlation, while as they get closer to +1.00, they create a strong positive correlation. This study has positive correlation values between all variables. Correlation values between the variables ranged between 0.858 and 0.983. According to this table, there is a strong correlation value between the number of other health workers and the number of nurses. The correlation values between the dependent and independent variables were calculated as 0.978 with the number of doctors, 0.956 with the number of nurses, 0947 with the number of midwives, 0.918 with the pharmacist, and 0.946 with the number of OHP.

Table 2
Correlation values between dependent and independent variables

Variables	Medical Doctors	Nurses	Midwives	Pharmacists	OHP
Hospitals	0.978	0.956	0.947	0.918	0.946
OHP	0.952	0.983	0.870	0.858	1.000
Pharmacists	0.961	0.929	0.981	1.000	
Midwives	0.972	0.931	1.000		
Nurses	0.979	1.000			

2.2. Linear Regression Model

There are two types of variables in regression analysis: dependent and independent. In short, regression analyzes are widely used to statistically detect the effects of independent variables on dependent variables. The symbol usually denotes the independent variables. The dependent variables affected by the independent variables are expressed with the symbol . A regression equation with one independent variable is formulated as follows (Cattaneo, Jansson, and Newey 2018):

$$y_{i,n} = \beta_i' x_{i,n} + \gamma_n' w_{i,n} + \mu_{i,n}, \qquad i = 1, \ldots, n \tag{1}$$

where, $y_{i,n}$ represents the dependent variable, and $x_{i,n}$ denotes the independent variable. The $w_{i,n}$ symbolizes the vector of covariates with the coefficient of γ_n' in the regression model, and β_i' signifies the coefficient of influence of the independent variable. The $\mu_{i,n}$ indicates the number of errors between the observed value and the predicted value. Since then, $w_{i,n} = 0$, $w_{i,n}$, was excluded from the formulation in this study. The following formula expresses linear regression models with multidirectional fixed effects according to data distributions and in non-interactive independent variable environments.

$$Y_{it} = \alpha_i + \beta_i' X_{it} + U_{it}, \qquad i = 1, \ldots, N, \ \ t = 1, \ldots, T \tag{2}$$

where Y_{it} represents the dependent variables and suppose that $Y_{it} = y_{(i-1)T+t,n}$ for $1 \le i \le N$ and $1 \le t \le T$. The constant value of the regression model is $\alpha_i, \alpha_i \in \mathbb{R}$. X_{it} represents the independent regressors and suppose that $X_{it} = x_{(i-1)T+t,n}$ for $X_{it} = X_{i1}, \ldots, X_{iT}$: $1 \le i \le n$. $U_{it} = U_{i1}, \ldots, U_{iT}$ are the values of errors equal to the i^{th} unit variables of dimension N and $U_{it} = U_{i1}, \ldots, U_{iT}$, $X_{it} = X_{i1}, \ldots, X_{iT}$: $1 \le i \le n$. There are multiple independent variables in this study. A regression equation with a large number of independent variables is expressed (Montgomery, Peck, and Vining 2012):

$$Y_{it} = \alpha_i + \beta_1' X_{1t} + \beta_2' X_{2t} + \beta_3' X_{3t} + \cdots + \beta_i' X_{it} + U_{it}, \quad i = 1, \ldots, N, \ \ t = 1, \ldots, T \tag{3}$$

In this study, the regression equation contains five independent variables and one dependent variable, according to the notations of the variables shown in Table 1. The equation is expressed as $Y_{it} = \alpha_i + \beta_d' X_{dt} + \beta_n' X_{nt} + \beta_m' X_{mt} + \beta_p' X_{pt} + \beta_o' X_{ot} + U_{it}$ for $i = 1, \ldots, N, \ t = 1, \ldots, T$. The regression equation resulting from the absence of interaction between the independent variables has a linear equation structure. In other words, the regression equation obtained in this study is an example of a linear regression equation.

2.3. Integer Optimization Models

Integer optimization models are used if the decision variables are integers; and the input and output decision variables have indivisibility problems (Öztürk 2016). Integer optimization models are generally defined as linear optimization models that adopt the constraint of integer decision variables. Linear mathematical modeling is created as follows (Bradley, Hax, and Magnanti 1977):

$$Maximize\ or\ Minimize \ \sum_{i=j}^{T} C_j x_j$$

Subject to

$$\sum_{j=1}^{T} A_{ij} x_j \le K_i \ \ for\ i = 1, 2, 3, \ldots, N_1 \tag{4}$$

$$\sum_{j=1}^{T} A_{ij} x_j = K_i \ \ for\ i = \ N_1 + 1 \ldots, N_2$$

$$\sum_{i=j}^{T} A_{ij} x_j \ge K_i \ \ for\ i = \ N_2 + 1 \ldots, N_3$$

$$X_j \ge 0, and\ j = 1, 2, 3, \ldots, T$$

where x_j represents the decision variable. A_{ij} and C_j are decision variable coefficients and constants. The value of K_i represents the right-hand-side value of the optimization model's constraints. The integer mathematical model is formulated as follows (Bradley et al. 1977):

$$Maximize\ or\ Minimize\ \sum_{i=j}^{T} C_j x_j$$

Subject to

$$\sum_{j=1}^{T} A_{ij} x_j \leq K_i \ \ for\ i = 1, 2, 3, \ldots, N_1 \quad (5)$$

$$\sum_{j=1}^{T} A_{ij} x_j = K_i \ \ for\ i = N_1 + 1 \ldots, N_2$$

$$\sum_{i=j}^{T} A_{ij} x_j \geq K_i \ \ for\ i = N_2 + 1 \ldots, N_3$$

$$X_j \geq 0, and \ \ integer, for\ j = 1, 2, 3, \ldots, T$$

If the decision variables are binary, the decision variable limits are expressed as $X_j = 0$ or $X_j = 1$. In such a case, the model constraint is described as follows:

$$\sum_{i=j}^{T} A_{ij} x_j = 1 \quad (6)$$

Optimization models created with such definitions are defined as integer assignment models (Winston and Venkataramanan 2002).

The second method of this study is the creation of integer optimization models. Optimization models are formed by determining the decision variables, objective function, constraints and limits, and the signs or types of the decision variables. While the decision variables of this study are independent factors, the objective function consists of the regression equation. Two types of optimization models were created for this study. The integer optimization method was used since the values of the decision variables in both optimization models are integers. In the first optimization model, the objective function equals an average number. The maximum value of the constraints is defined as the average value they have for 52 years. This optimization model is built as follows:

$$Y_{it}\{\alpha_i + \beta_d' X_{dt} + \beta_n' X_{nt} + \beta_m' X_{mt} + \beta_p' X_{pt} + \beta_o' X_{ot} + U_{it}\} = \bar{Y}_{it}$$

Subject to the constraints:

$$l_d^t \leq X_{dt} \leq \bar{u}_d^t$$

$$l_n^t \leq X_{nt} \leq \bar{u}_n^t$$

$$l_m^t \leq X_{mt} \leq \bar{u}_m^t \quad (7)$$

$$l_p^t \leq X_{pt} \leq \bar{u}_p^t$$

$$l_o^t \leq X_{ot} \leq \bar{u}_o^t$$

$$t = \{1967, 1968, \ldots, 2018\}$$

$$X_{dt}, X_{nt}, X_{mt}, X_{pt}, X_{ot} \geq 0, and\ integer$$

where, y_{hs} represents the mean of the values of the objective function over 52 years. $l_d^t, l_n^t, l_m^t, l_p^t,\ l_o^t;\ t = \{1967, 1968, \ldots, 2018\}$ are the minimum values of the variables. $\bar{u}_d^t, \bar{u}_n^t, \bar{u}_m^t, \bar{u}_p^t,\ \bar{u}_o^t;\ t = \{1967, 1968, \ldots, 2018\}$ data represents the average of the values of the independent variables over 52 years. The second optimization model developed for this study, the objective function, was created to calculate the optimum values the independent variables can have when the number of hospitals at the current maximum level is obtained. The second optimization model is expressed as mathematical equations as follows:

$$Maximize\ Y_{it} = \{\alpha_i + \beta_d' X_{dt} + \beta_n' X_{nt} + \beta_m' X_{mt} + \beta_p' X_{pt} + \beta_o' X_{ot} + U_{it}\},$$

Subject to the constraints:

$$\begin{gathered} l_d^t \le X_{dt} \le \bar{u}_d^t \\ l_n^t \le X_{nt} \le \bar{u}_n^t \\ l_m^t \le X_{mt} \le \bar{u}_m^t \\ l_p^t \le X_{pt} \le \bar{u}_p^t \\ l_o^t \le X_{ot} \le \bar{u}_o^t \\ t = \{1967, 1968, \ldots, 2018\} \\ X_{dt}, X_{nt}, X_{mt}, X_{pt}, X_{ot} \ge 0, and\ integer \end{gathered} \tag{8}$$

where, $u_d^t,\ u_n^t,\ u_m^t,\ u_p^t,\ u_o^t;\ t = \{1967, 1968, \ldots, 2018\}$ are the maximum values of the independent variables. Minitab 18.01 computer statistics program was used both for statistical analysis and for the solution of optimization models. The findings obtained from the study methods are included in the third part.

3. FINDINGS OF THE STUDY

A two-stage method was used for this study. Regression analysis, the first method, was performed and tested whether the independent factors affected the dependent factor. In addition, the accuracy percentages of the statistical analysis (variation percentages of the response variable specified by the linear regression model) were calculated as R^2 = 97.85%, $R^2_{adjusted}$ =97.62%, and $R^2_{predicted}$ =97.62%, respectively. While predicted R^2 is used in statistical regression models due to the complexity of the models with more than one variable, adjusted R^2 is used to compare the reliability power between regression models containing a different number of variables and univariate models. The R^2 values obtained in this study are high, and the reliability of the obtained results has been tested. Statistical effects of dependent and independent variables are given in

Table 3
The results of statistical analysis

Variables	Coefficient of Regression	Sum of Squares	Mean of Squares	t-value	f-value	p-value
X	0.00029	48,000	48,000	0.15	0.020	0.880
X_n	-0.00970	44245	44245	-4.62	21.36	0.001
X_m	0.01681	51518	51518	4.99	24.88	0.001
X_p	0.00315	572,00	572,00	0.53	0.280	0.602
X_o	0.00999	50034	50034	4.92	24.16	0.001

According to , the numbers of the nurse (p value=0.001, f value=21.36, t value=-4.62), midwives (p value=0.001, f value=24.88, t value=4.99), and OHP (p value=0.001, f value=24.16, t value=4.92) were found to be effective on the number of hospitals. Still, the number of doctors and pharmacists was inadequate for the number of hospitals, with a margin of error of 1.00% or 5.00%. However, if the number of doctors and pharmacists is evaluated within the margin of error of 10%, we can assume that they affected the outcome. While the increase in the number of health institutions also causes an increase in some healthcare resources, some of them should not be employed too much. By obtaining the regression coefficients of the dependent and independent variables, the regression equation has emerged as follows:

$$Y_{it} = 536{,}6 + 0{,}00029X_{dt} - 0{,}00970X_{nt} + 0{,}01681X_{mt} + 0{,}00315X_{pt} + 0{,}00999X_{ot} + U_{it} \tag{9}$$

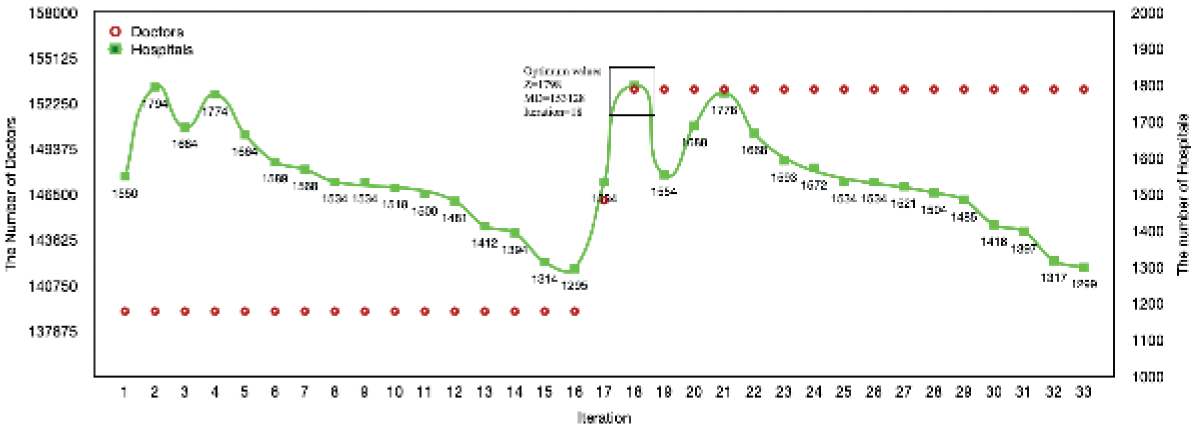
According to this equation, of the five independent variables, only the number of nurses, had a negative effect on the number of hospitals. It is understood that other independent variables positively impact the number of hospitals. This regression equation is also considered the objective function of the optimization models developed. The optimum values obtained by running the first and second optimization models are shown in Table 4.

Table 4
The optimum results of dependent and independent variables

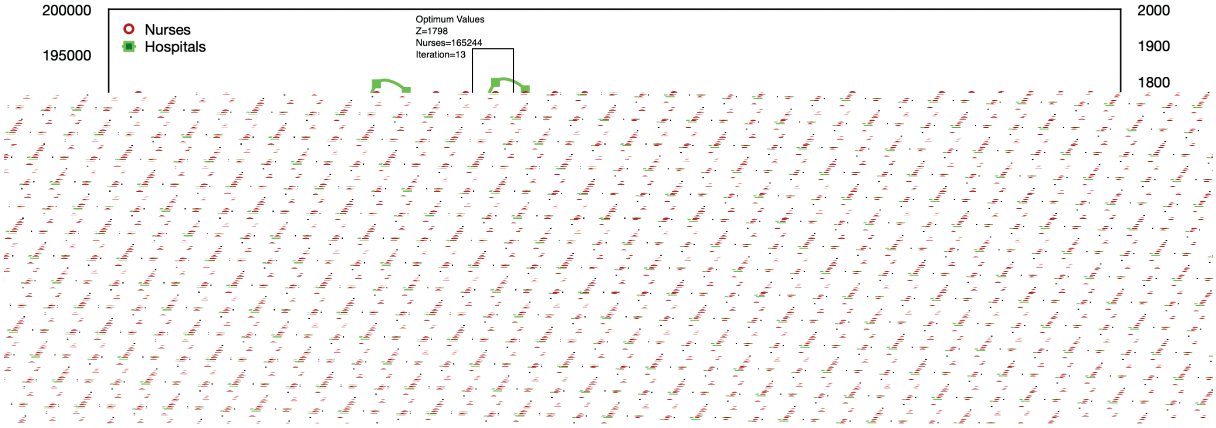
Optimization Models	Objective functions	Decision Variables				
		X_d	X_n	X_m	X_p	X_o
Model 1,	1263,99 ~ 1264	60999,29 ~ 60999	16545,90 ~ 16546	15145,25 ~ 15145	12887.26 ~ 12887	57581.173 ~ 57581
Model 2,	1458,09 ~ 1458	139105,617 ~ 139106	165244,26 ~ 165244	48796,89 ~ 48797	25500,35 ~ 25500	156824,39 ~ 156824

Table 4 was converted to integers when healthcare resources could not be expressed as fractions. According to optimization model 1, the objective function was calculated as 1,264. The optimum health resource numbers to be employed in 1,264 hospitals were calculated as 60,999 doctors, 16,546 nurses, 15,145 midwives, 12,887 pharmacists, and 57,581 OHP. According to the second optimization model, the optimum number of hospitals was 1,458. According to the optimum number of hospitals, 13,9106 doctors, 16,5244 nurses, 48,797 midwives, 25,500 pharmacists, and 156,824 OHP should be employed. The closest value to the number of 1,458 hospitals is the data for 2011. While the number of hospitals operating in 2011 is 1,453, the number of doctors employed is 126,029, the number of nurses is 124,982, the number of midwives is 51,905, the number of pharmacists is 26,089, and the number of OHP is 110,862. As a result of the optimum values obtained, we determined that the employment of doctors, nurses, and OHP is low, while the employment of midwives and pharmacists is high compared to 2011 data.

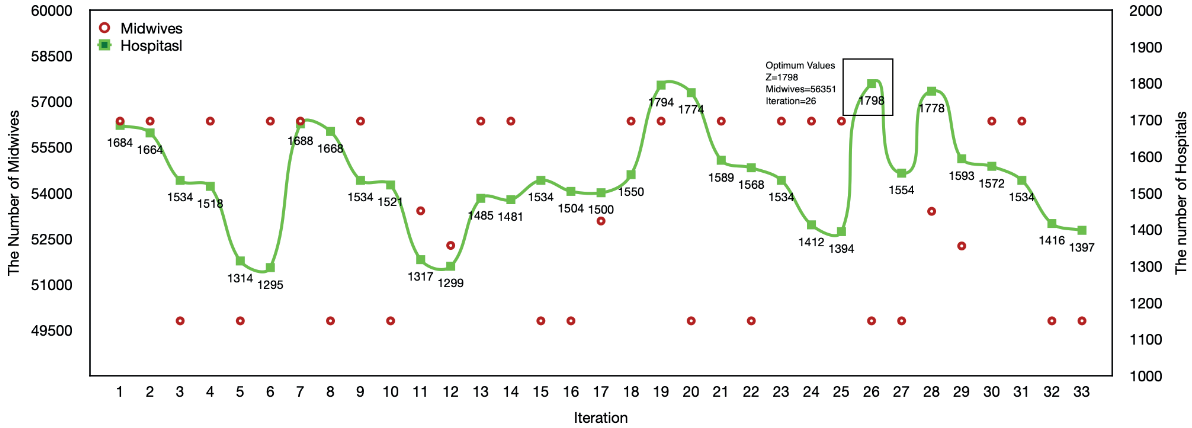
Calculating how many hospitals should provide healthcare services according to the maximum and minimum values of the existing independent variables is shown in . According to these figures, the maximum number of hospitals was calculated as 1,798 without limiting the objective function. While maximizing the number of hospitals, the limits of the decision variables did not change. In other words, how many hospitals will operate with the existing health workers (the numbers may vary within limits) without employing extra health workers has been optimized. The optimum number of health workers required to provide health services in 1,798 hospitals was calculated as 153,128 doctors, 165,244 nurses, 56,351 midwives, 32,032 pharmacists, and 177,409 OHP. They obtain optimum results by arranging the numbers of each healthcare worker from the lowest to the highest, corresponding to different iterations. According to these results, 25,255 nurses are overworked in the Turkish Healthcare System.



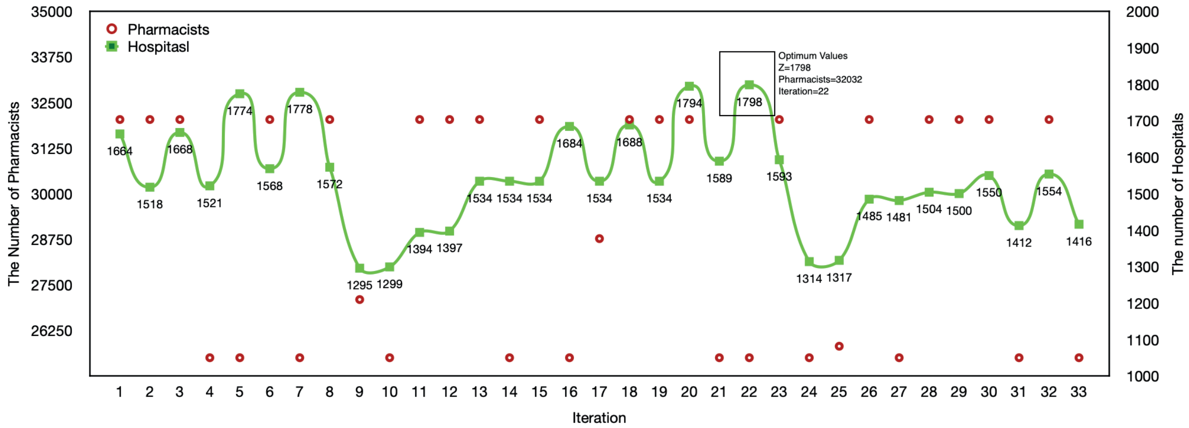
(a)


200000
195000
Nurses
Hospitals
Optimum Values
Z=1798
Nurses=165244
Iteration=13
2000
1900
1800

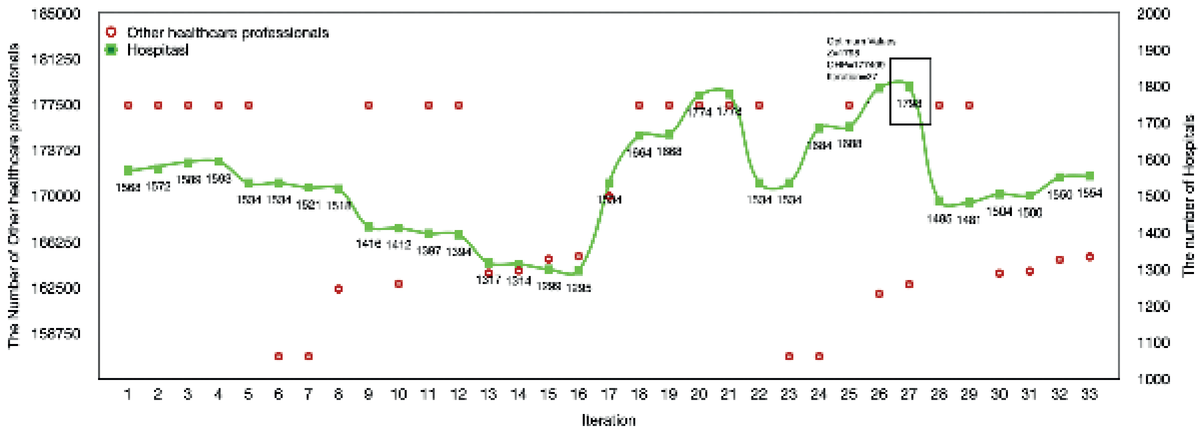
(b)


Midwives
Hospitasl
Optimum Values
Z=1798
Midwives=56351
Iteration=26
The Number of Midwives
60000
58500
57000
55500
54000
52500
51000
49500
The number of Hospitals
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
1684 1664 1534 1518 1314 1295 1688 1668 1534 1521 1317 1299 1485 1481 1534 1504 1500 1550 1794 1774 1589 1568 1534 1412 1394 1798 1554 1778 1593 1572 1534 1416 1397
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 32 33
Iteration

(c)


Pharmacists
Hospitasl
Optimum Values
Z=1798
Pharmacists=32032
Iteration=22
The Numbeer of Pharmacists
35000
33750
32500
31250
30000
28750
27500
26250
The number of Hospitals
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
1664 1518 1668 1521 1774 1568 1778 1572 1295 1299 1394 1397 1534 1534 1534 1684 1534 1688 1534 1794 1589 1798 1593 1314 1317 1485 1481 1504 1500 1550 1412 1554 1416
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 32 33
Iteration

(d)



(e)

Figure 7. Number of Healthcare Professionals for the Maximum Number of Hospitals
(a-the number of doctors, b-the number of nurses, d-the number of midwives,
d-the number of pharmacists, e-the number of OHP) (Z: objective function)

The optimization model developed in this study will contribute to the determination of the optimum number of healthcare resources needed according to the number of hospitals that operating in the future. Thus, efficient and sufficient use of health resources will be ensured in the healthcare systems of countries. Efficient use of healthcare resources is one of the critical issues in health system management. While health resource planning is done in health management, there are more effective ways to use available resources. The employment of health personnel in existing health institutions does not disrupt the service or recruitment of personnel for new health institutions. In new health institutions, there are two situations that can affect the employment of health personnel and their utilization.. In the first situation, the institution must determine how best to utilize existing health personnel, but the main issue of health management is to deal with the second case, which causes problems in terms of costs. In other words, it is preferred in health management to keep existing resources and expense costs constant and to get more efficiency (Ceylan and Atalan 2021). Although this situation may seem appropriate for small-scale communities or health institutions, if it is examined in terms of patient population and number of institutions, the lack of many health resources can cause disadvantages (for example, long waiting times, staff and patient dissatisfaction, a small number of patients being examined or treated, etc.). Balancing the two situations should be decided by looking at the changes in healthcare systems.

4. DISCUSSION AND CONCLUSION

The integer optimization models were created using the response optimization method to facilitate healthcare resource planning by using the data on the number of health resources from 1967 to 2018 in Turkey in this study. The number of hospitals was considered the dependent variable, while the number of doctors, nurses, midwives, pharmacists, and OHP were defined as the independent variable. Linear regression and integer optimization methods were used in this study. In regression analysis, the number of nurses, midwives, and OHP was effective on the number of hospitals, but the number of doctors and pharmacists was only effective on the dependent variable, according to a 10% margin of error. Two optimization models were developed by determining the limits of the decision variables with the obtained regression equation. Optimum results were obtained for the number of healthcare resources employed by taking the average number of hospitals operating in the first model 52 years. In the second optimization model, the optimum values of the healthcare resources used were calculated by maximizing the number of hospitals. The number of doctors, nurses, and midwives from health resources is low, but the number of other health resources is high, according to the results obtained from the second optimization model.

The number of hospitals is increasing day by day to meet human needs. There may be many reasons for this increase, such as the population, the desire to live longer, etc. However, an increase in the number of healthcare resources is considered normal only after ensuring that efficiency from the existing healthcare resources is sufficient. Increasing the number of healthcare resources in a healthcare institution does not mean that that institution will obtain higher efficiency. Advantages such as the increase in the number of patients treated, reduced patient waiting time, and decreased patient examination/treatment costs are not directly proportional to increasing the number of healthcare resources. Many processes, such as patient flow diagrams, examination/treatment procedures, and communication between resources, must be examined well to reveal such benefits.

For future studies, the number of healthcare resources can be calculated using the data used in this study and the estimation methods such as machine learning and time series. The number and types of dependent and independent variables can be increased or decreased by considering the healthcare cost data. Another research topic is the optimum number of health resources calculated by calculating the labor costs of healthcare resources for a hospital. For this reason, this study will contribute significantly to the literature and be an essential source for future studies.

Peer-review: Externally peer-reviewed.
Conflict of Interest: The author has no conflict of interest to declare.
Grant Support: The author declared that this study has received no financial support.

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