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Research Article

A bi-objective model for Cancer hospitals' location and cancer patients' allocation in Iran

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Abstract

Background and objective: Cancer curing is a costly problem for either healthcare systems and patients in many countries. Cancer hospitals can provide all needed services simultaneously and increase cancer patients' satisfaction by decreasing fatigue and stress. In this paper, constructing efficient cancer hospitals in proper locations and also allocating cancer patients to the nearest destination are considered to prevent the waste of money and cancer patients' medical traveling problems.

Methods: A bi-objective mixed-integer linear mathematical model is developed to locate the cancer hospitals in candidate regions and allocate the cancer patients to proper destinations. The first objective minimizes the total costs, consisting of cancer hospital construction costs and the cancer patients' traveling-accommodation costs. The secondary one maximizes the bed capacity efficiency via minimizing the over-plus of bed capacity. The model is solved by applying an optimality grade approach in are solved using the CPLEX solver of GAMS 24.1.2 software. The historical data of cancer patient's population was derived from annual reports of the cancer office in Iran's ministry of health and medical education. The linear regression models are fitted in Minitab software to predict the number of cancer new cases in Iran provinces until 2040.

Results: Model's solving results show that twenty-six provinces are selected to construct at least one cancer hospital there, and six provinces with the lowest density of cancer patients' population such as Ilam and Markazi are not opted as locations to construct cancer hospitals. In addition, the needed budget to establish all allocated cancer hospitals will be approximately 150 billion USD.

Conclusion: To conclude, the results of the proposed model solving represents that most provinces of Iran need at least one cancer hospital in the next two decades. This verifies the need for having strategic planning in Iran's cancer hospital network at present.

Keywords: Cancer Hospitals, Bed capacity Efficiency, Hospital Location, Cancer Patients' Allocation, Optimality Grade

Background and objective

Introduction: Cancer is the second cause of death in many countries worldwide. The global cancer burden is estimated to have risen to 29.5 million new cases and 16.4 million deaths in 2040[1]. Cancer care imposes billions of dollars on the countries based on the population size, age distribution, healthcare delivery systems, employment patterns, cancer incidence, and mortality rates. For instance, the total cost of cancer was €199 billion in Europe (EU-27 plus Iceland, Norway, Switzerland, and the United Kingdom) in 2018[2]. Specialized cancer hospitals can make the cancer treatment process regular and reduce delays and stress. Cancer incident is going to increase worldwide, and this is an alarm to governmental authorities to provide needed resources as soon as possible.

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Literature review: Chu and chu (2000) proposed some models based on various scenarios of public hospital location and service allocation in Hong Kong for the future years till 2006[3]. Mitropoulos et al. (2006) used the distance between patients and facilities and the equitable distribution of the facilities among citizens as two objective functions of a mathematical programming model to deal with the location problem of hospitals and primary health care centers under interdependency considerations between locations[4]. Syam and cote (2010) developed a model for the location and allocation of specialized health care services, such as traumatic brain injury (TBI) treatment. The simulated annealing metaheuristic method is used to minimize the cost objective function of the model in some high dimension examples [5]. Mestre et al. (2014) proposed two location-allocation models for hospital network design under uncertainty and applied to a case study in Portuguese. The ε-constrained method is used to solve the proposed bi-objective location-allocation models[6]. Zahiri et al. (2014) presented a single objective, total cost, multi-period robust possibilistic programming model for a multi-period location-allocation problem in an organ transplant supply chain under uncertainty. The model is solved by a solver of GAMS 22.9 software for a real case of organ transplant supply chain in Iran[7]. Beheshtifar and Alimoahmmadi (2014) considered the location-allocation problem in establishing new healthcare facilities and determining their optimal number and locations in Iran. They used a combination of a geographical information system (GIS) analysis and a multi-objective genetic algorithm to solve the proposed four-objective model[8]. Zarrinpoor and et al. (2017) proposed a new reliable hierarchical location-allocation model for health service network designs under consideration of disruption risk for facilities. The Benders decomposition algorithm is the base of the solution procedure[9]. Wang and et al. (2018) mentioned the trade-off between social, economic, and environmental factors in a four-objective hierarchical location-allocation model. A bi-level multi-objective particle swarm optimization algorithm has been developed to make the binary location and capacity determination decisions, simultaneously[10]. Sathler et al. (2018) proposed a mathematical model for solving a location problem of Medical Specialties Centers (MSCs) and medical care equipment allocation. The model helps to balance the demand attendance for specialists and medical exams and the availability of specialists and new equipment[11]. Ebrahimi et al. applied fuzzy TOPSIS to choose the optimal place to build a hospital in Malayer. They considered the population density, distance to other hospitals, access to main roads, and distance to industrial and military centers as effective factors[12]. These parameters are combined ordinary by. Viera et al. (2019) solved a p-median hierarchical location model to minimize the distance between the patient's region and cancer-treating units. They used CPLEX optimization software to solve the model based on data gathered from the capital of Brazil[13]. Adali and Tus (2019) used TOPSIS and some other Multiple Attribute Decision Making (MADM) methods to select the location of a private hospital in Denizli in Turkey[14]. Kaveh et al. (2020) improved the Genetic Algorithm(GA) to solve a hospital location and population allocation problem. They aimed the GIS and Analytical Hierarchical Analysis(AHP) methods to select the locations[15]. Kamali et al. (2020) considered a scenario-based emergency medical centers location problem. They combined the optimization and simulation to locate these centers in Isfahan in Iran and allocate the ambulances to located centres[16]. Halawa et al. (2020) considered the healthcare facilities' planning problem and reviewed the publications between 2008 and 2018[17].

Contribution: Although cancer is a deadly and costly disease, no notable researches have not been done about cancer supply chain planning yet. This paper focuses on the cancer hospital location-allocation problem. Total costs of location-allocation and bed capacity efficiency are two considered objective functions. Several scenarios are mentioned as cancer hospitals' bed capacity to construct hospitals efficiently. We solve the model in the case of Iran, a country with an increasing rate of cancer incidents. All parameters are predicted for the year 2040. The time value of money is a basic concept in the engineering economy that originated from the interest rate and is applied to forecast of the future value of the proposed model's costs in 2040[18]. Moreover, the simple linear regression model is applied to forecast the cancer incidents in each province[19,20]. Furthermore, we use the optimality grade to transform the bi-objective model into a single objective model[21,22].

Methods

To locate cancer hospitals in Iran's provinces and allocate the cancer patients to proper destinations, we follow the steps presented in Figure 1.

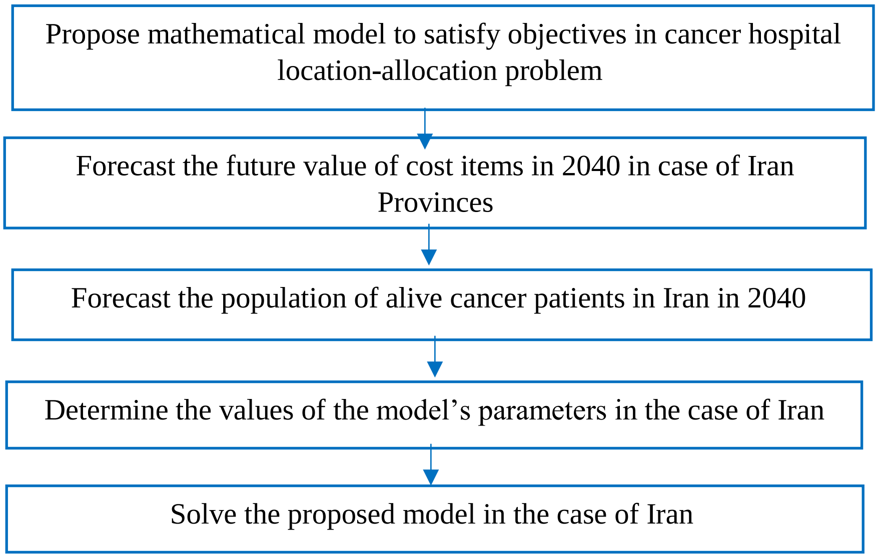

Figure 1. Schematic representation of model developing

Future value of money: To forecast the future value of traveling and cancer hospital establishing costs, we use the time value of money concept and corresponded factors. Equation 1 consists of a factor to calculate the future value of C units of money after n years.

$$F = C(1+i)^n \qquad (1)$$

Where i is the annual interest rate, and F is the future value.

Simple linear regression model: A simple linear regression model can predict the dependent variable y based on various values of independent variable x, equation 2.

$$y = a + bx \tag{2}$$

Where, a is the intercept parameter, and b is the slope parameter. Equations 3 and 4 represent the estimation formulas to calculate the value of a and b, respectively, based on n sample couples $(x_1, y_1), (x_2, y_2), ..., (x_n, y_n)$.

$$b = \frac{\sum_{i=1}^{n} x_i y_i - \frac{(\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{n}}{\sum_{i=1}^{n} x_i^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}} \tag{3}$$

$$a = \frac{\sum_{i=1}^{n} y_i}{n} - \left(\frac{\sum_{i=1}^{n} x_i y_i - \frac{(\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i)}{n}}{\sum_{i=1}^{n} x_i^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}}\right) \times \tag{4}$$

$$\left(\frac{\sum_{i=1}^{n} x_i}{n}\right) = \frac{\sum_{i=1}^{n} y_i}{n} - b\frac{\sum_{i=1}^{n} x_i}{n}$$

The coefficient of determination is an index to validate the fitted regression. The greater coefficient of determination, the more aptness of the regression model. The simple linear regression model of each Iran's province will be fitted in MINITAB software.

The fuzzy approach to transforming multi-objective models: A fuzzy number $\tilde{A}$ is defined as a couple of $(x, \mu(x))$, and $\mu(x)$ is the membership function or membership grade. Suppose there is a multi-objective model as equation 5.

$$\begin{aligned} \min \quad & z_1 = f_1(X) \\ \min \quad & z_2 = f_2(X) \\ & \vdots \\ \min \quad & z_n = f_n(X) \\ s.t. \quad & \\ & AX \le B \end{aligned} \tag{5}$$

Where, $AX \le B$ is a set of constraints.

The minimum value of each objective function (z^l) can be derived through a single objective minimization of its own separately, and the maximum value (z^u) could be determined via maximizing the single objective model. In a multi-objective model, there is no guarantee to reach the optimum value of all objective functions. In other words, each objective function takes a value between its minimum and maximum values due to the optimum solution of the multi-objective model. By using the concept of fuzzy numbers membership function, the optimality grade of the ith objective function is defined in equation 6.

$$\mu_{Z_i}(z_i) = \begin{cases} 1 & z_i \le z_i^l \\ \frac{z_i^u - z_i}{z_i^u - z_i^l} & z_i^l \le z_i \le z_i^u \\ 0 & z_i \ge z_i^u \end{cases} \tag{6}$$

Where, $\lambda = \min\{\mu_{Z_i}(z_i); \quad i = 1, 2, ..., n\}$ and so $0 \le \lambda \le 1$. Figure 2 shows a graphical representation of the optimality grade of Z_i.

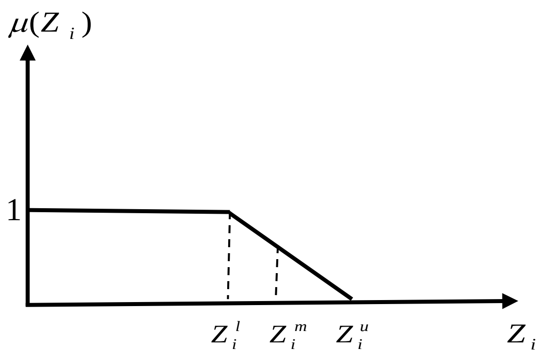

Figure 2. The optimality grade of Z_i

The maximum value of λ can lead to a good combination of values of all n objective functions. The multi-objective model presented in equation 5 can be easily transformed into a single objective model represented in equation 7.

$$\max \lambda$$
$$s.t.$$
$$\lambda \le \frac{z_i^u - z_i}{z_i^u - z_i^l} \qquad i = 1,2,...,n \qquad (7)$$
$$AX \le B$$
$$0 \le \lambda \le 1$$

All corresponded models will be solved by the CPLEX solver in GAMS software.

Problem description: Lacking a good scatter of cancer diagnostic and curing centers could force the cancer patients to travel to another city or even country to receive the required services at an acceptable quality level. It is the consequence of the concentration of high-quality cancer treatment resources in major cities. Moreover, there may not be proper cancer centers in many cities. Cancer patients will suffer from Long travels, fatigue, and stress and endure high costs of traveling and accommodation of family. Proper distribution of cancer diagnostic and treatment centers across a country can facilitate access to cancer services. Consequently, an efficient plan for cancer hospital distribution is a good help for both authorities of health care systems and cancer patients altogether. In other words, determining the location of cancer hospitals in efficient bed capacity, and allocation of cancer patients to the closest destinations are important decisions to make.

Commonly, the cancer hospitals are constructed in high bed capacity to reach high efficiency because of the high expenses per specialized cancer bed establishing. For example, Anderson cancer center in Houston of United States of America has 700 beds, Mayo Clinic in Rochester of the United States of America has 1318 beds, National cancer center in Goyang of South Korea has 500 beds, and Macarthur cancer service in Sydney of Australia has 306 beds. Consequently, cancer hospitals' capacity of 300, 500, or 1000 beds is popular. We propose a bi-objective mathematical model not only to select the lowest cost of cancer hospital locations and cancer patient's allocation, but also to reach the highest cancer hospitals' bed capacity efficiency considerations. The location of cancer hospitals, the allocation of cancer patients to destinations, and the combination of cancer hospitals in predefined bed capacity are the expected outputs of model solving.

Model Assumptions:

The major important supposed assumptions are as follows:

-The sets of candidate location regions and demand regions are known.

-Demand (cancer patients number) and costs are deterministic parameters.

-The patients of a demand region can be allocated to one or more neighbor candidate regions.

-To achieve the right level of productivity, cancer hospitals can be built in a predetermined capacity such as 300, 500, or 1000 beds.

Sets:

i: Index of demand region $(i = 1,2,...,N)$,

j: Index of location candidate region $(j = 1,2,...,N)$,

s: Index of predefined hospital bed capacity $(s = 1,2,...,S)$.

Parameters:

de_i: The number of cancer patients of demand region *i*,

d_{ij}: Distance between demand region *i* and location candidate region *j*(km),

$\max_{ij}$: The maximum number of patients

$$\min \quad Z_1 = \sum_{i=1}^{N}\sum_{j=1}^{N} c_{ij} d_{ij} Q_{ij} + \sum_{j=1}^{N}\sum_{s=1}^{S} cv_j bc_s M_{sj} \tag{8}$$

$$\min \quad Z_2 = \sum_{j=1}^{N} \left(\sum_{s=1}^{S} bc_s M_{sj} - V_j\right) \tag{9}$$

s.t:

$$\sum_{j=1}^{N} Q_{ij} = de_i \quad \forall i = 1,\dots,N \tag{10}$$

$$V_j = \alpha \times \sum_{i=1}^{N} Q_{ij} \quad \forall j = 1,\dots,N \tag{11}$$

$$\sum_{i=1}^{N} Q_{ij} \le M \times Y_j \quad \forall j = 1,\dots,N \tag{12}$$

$$\sum_{j=1}^{N} a_{ij} Y_j \ge 1 \quad \forall i = 1,\dots,N \tag{13}$$

$$Y_j \le \sum_{i=1}^{N} Q_{ij} \quad \forall j = 1,\dots,N \tag{14}$$

$$Q_{ij} \le a_{ij} \times \max_{ij} \quad \forall i = 1,\dots,N;\ j = 1,\dots,N;\ i \ne j \tag{15}$$

$$V_j \ge \min_j \times Y_j \quad \forall j = 1,\dots,N \tag{16}$$

$$V_j \le \sum_{s=1}^{S} bc_s M_{sj} \quad \forall j = 1,\dots,N \tag{17}$$

$$M_{Sj} \le u_s Y_j \quad \forall j = 1,\dots,N;\ s = 1,2,\dots,S \tag{18}$$

$$Q_{ij}, V_j \ge 0; Y_j \in \{0,1\}; M_{sj} \in N \quad \forall i = 1,\dots,N;\ j = 1,\dots,N;\ s = 1,2,\dots,S \tag{19}$$

that can be allocated from demand region *i* to location candidate region *j*,

c_{ij}: Traveling cost of each cancer patient from demand region *i* to location candidate region *j* per distance,

cv_j: Cost of providing one bed in a cancer hospital in location candidate region *j*

$\min_j$: Minimum required cancer bed capacity that makes it possible to construct at least one cancer hospital in location candidate region *j*,

α: Annual consumption coefficient per bed in a cancer hospital for each cancer patient,

bc_s: predefined cancer hospital bed capacity s

k_j: Importance weight of demand region *j* regarding the therapeutic justice increase

u_s: upper bound of the number of selective cancer hospitals by bed capacity bc_s

a_{ij}: 1 if it is possible to allocate cancer patients from demand region *i* to location candidate region *j* and 0 otherwise,

M: A great number.

Decision variables:

Q_{ij}: the number of cancer patients allocated from demand region *i* to location candidate region *j*

Y_j: 1 if at least one cancer hospital located in location candidate region *j*

V_j: The number of required specialized cancer beds in location candidate region *j*

M_{sj}: The number of bc_s-bedded cancer hospitals in location candidate region *j*

Mathematical model: The objective functions and constraints of the proposed mixed-integer linear programming model are introduced in equations 8-9 and 10-19, respectively.

The first objective function (Z_1), equation 8, consists of two parts, which are cancer patient's traveling costs and cancer hospitals' construction costs, respectively. Equation 9 introduces the second objective function (Z_2), efficiency in cancer hospitals bed capacity allocation. Constraint (10) ensures that all demands are met. Constraint (11) shows the mathematical relation between the number of patients allocated to each location candidate region and the needed bed in that region. Constraint (12) ensures that cancer patients can be referred to one location candidate region only when at least one cancer hospital is constructed in that region.

Constraint (13) ensures that the cancer patients of each demand region have been allocated to at least one of the located regions. Constraint (14) ensures that only when at least one cancer patient is referred to a location candidate region, that location must be selected for cancer hospitals construction. Constraint (15) ensures that the number of cancer patients from every demand region referred to a different possible neighbor location candidate region does not exceed an upper limit. Constraint (16) ensures that the bed capacity of selected locations must be greater than a lower bound. This lower bound guarantees the achieving of the least efficiency in cancer hospital construction. Constraint (17) ensures that various cancer hospitals can cover the needed bed capacity in every located region. Constraints (18) give upper bounds to the number of each predefined bed capacity. Constraint (19) defines the type of decision variables.

Results

As many countries all over the world, according to the Iran Ministry of Health and Medical Education's reports, nowadays, cancer is a major public health problem and is the second leading cause of death in Iran. International Agency for Research on Cancer (IARC) forecasted that there would be 238000 incidents of cancer in Iran only in the year 2040. It is estimated that the direct treatment costs of cancer in Iran is about $0.4 billion in 2020.

Current situation: In Iran, specialized centers for cancer diagnosis and treatment services are usually concentrated in a few major cities such as Tehran (Mahak cancer hospital (100 beds), cancer center of the west of Tehran (64 beds)), Isfahan (Seyyedoshohada cancer hospital (185 beds)), Shiraz (Amir cancer hospital (94 beds)), Mashhad (Nazeran cancer Hospital (200 beds), Omid cancer hospital (110 beds)), etc. All existing Iranian cancer hospitals have a low level of bed capacity, which could declare the hospital's efficiency. The concentration of cancer treatment facilities in some major provinces such as Tehran, Mashhad, Isfahan, and Shiraz not only can lead to cancer patients traveling from undeveloped provinces to these major cities but also may conclude the long queues in receiving cancer-curing services in major cities. Figure 3 shows the current situation of cancer patients traveling between Iran provinces nowadays approximately.

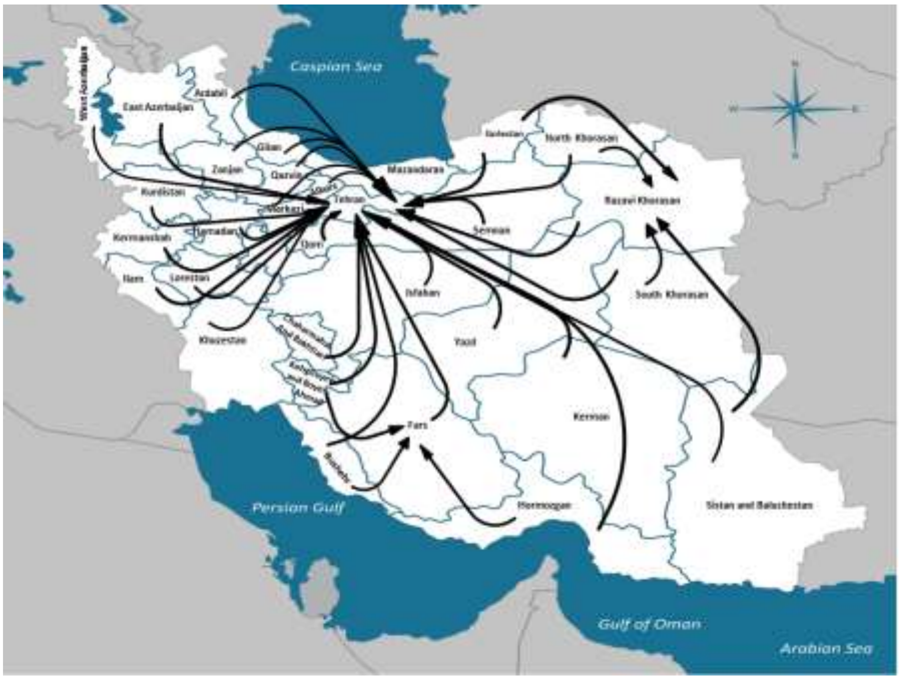

Figure 3. The current situation of cancer patients' traveling between Iran provinces (2020)

Data gathering: Conventionally, the cancer statistics are reported in a standard measure named ASR (Age Standardised Rate). For instance, when the value of ASR is equal to 124, it means that there were 124 cases of cancer per 100000 individuals of the studied population and year. Iran Ministry of Health and Medical Education has published the statistics of cancer incidents in all 31 provinces of Iran divided on the cancer type and patient gender in the format of ASR in some recent years. Therefore, trends of cancer occurrence in each province and also between provinces are comparable based on not only the type of cancer but also the gender of patients. For instance, the statistics of ASR related to all cancer types in various provinces of Iran are shown in Table 1.

Table 1. ASR of cancer incidence in provinces of Iran (2003-2009,2014)

No.	Province	2003	2004	2005	2006	2007	2008	2009	2014
1	Tehran	138	74	92.5	104	99.5	187.5	160	194.5
2	East Azerbaijan	20.5	82.5	46	42.5	133.5	162.5	148	193.5
3	Razavi Khorasan	97.5	106	80.5	133.5	128.5	145.5	138	197
4	Alborz	138	74	92.5	104	99.5	187.5	160	129.5
5	Khuzestan	51.5	73	67.5	81.5	103.5	155	137	159
6	Isfahan	74	101	109	121	127.5	139.5	156.5	188.5
7	Fars	63.5	66	81.5	92.5	132	134.5	132.5	166.5
8	Gilan	50	73	111.5	103.5	121	137.5	125	126
9	West Azerbaijan	75.5	100.5	100.5	97.5	108.5	92	111	206
10	Mazandaran	70	91	97.5	109	100	144	131	151
11	Kerman	59.5	74	66.5	84.5	79	98	130	176.5
12	Hamadan	52.5	60.5	82	97.5	101.5	134.5	123.5	142.5
13	Lorestan	44	78.5	70.5	78	91	129.5	105	118
14	Kurdistan	64.5	91.5	89.5	98	103.5	155	132	135.5
15	Golestan	52.5	74.5	72.5	90	87.5	93.5	91	169.5
16	Yazd	111.5	104	108	113	118.5	163.5	166	224
17	Zanjan	53.5	71	78	81.5	90	84	78	208.5
18	Ardabil	52	104.5	65	101.5	76.5	120	111.5	173.5
19	Kermanshah	81.5	85.5	89	86.5	116.5	130	118.5	129
20	Markazi	44.5	61.5	73	83	88	93.5	166	121
21	Sistan and Baluchestan	17.5	20.5	27.5	32	34.5	34.5	35.5	95.5
22	Qom	60	80.5	71.5	84	85.5	93.5	59.5	*
23	Qazvin	83.5	90	95	96	99.5	115.5	104.5	160
24	Hormozgan	19.5	43.5	39	49.5	51.5	56.5	45.5	102.5
25	Bushehr	34.5	55.5	66	70.5	77.5	81	79.5	149
26	North Khorasan	97.5	106	67.5	37	68	89.5	88.5	160
27	South Khorasan	97.5	106	67.5	54	64.5	90.5	79.5	143.5
28	Semnan	57.5	76.5	78	99	108.5	198	128.5	171
29	Chaharmahal and Bakhtiari	51	95.5	78	87.5	96.5	99	89.5	146
30	Kohgiluyeh and Boyer-Ahmad	7	84	54.5	76	88	87	100	159
31	Ilam	38.5	68	42	75.5	88	86.5	72.5	135

Parameters determination: We need the cancer patient population size of each province in 2040 as a demand parameter to solve the proposed model. For this, five following steps are passed:

Step 1. Gathering data of ASR in each province from existing governmental reports.

Step 2. Transforming the ASR to annual cancer new cases based on the province's population

size

Step 3. Forecasting the cancer new cases in each year until 2040 by using simple linear regression fitted in Minitab software (Table 2).

Step 4. Determining the number of all cancer patients alive each year until 2040 by considering 0.2 as the annual cancer patients' death rate (Table 2).

Table 2. Demand forecasting results

No.	Province	Data gathering period	The fitted simple linear regression model	R^2_{adj}	Number of cancer
1	Tehran	2004-2006, 2009, 2014	$y=-2786638+1396x$	0.937	276451
2	East Azerbaijan	2003, 2004, 2007-2009	$y=-1674759+836.7x$	0.914	143723
3	Razavi Khorasan	2003, 2004, 2006-2010	$y=-1420185+711.5x$	0.954	142104
4	Alborz	2004-2006, 2008	$y=-1328291+663.4x$	0.902	111961
5	Khuzestan	2003, 2004, 2006-2009	$y=-1225343+612.8x$	0.940	111505
6	Isfahan	2003-2009, 2014	$y=-1039474+520.9x$	0.960	105134
7	Fars	2004-2006, 2014	$y=-787482+394.5x$	0.990	78393
8	Gilan	2003-2005, 2008, 2007	$y=-822713+411.4x$	0.886	74511
9	West Azerbaijan	2003-2007, 2014	$y=-544936+273.2x$	0.957	56306
10	Mazandaran	2003-2005, 2007, 2009, 2014	$y=-361672+263.2x$	0.947	51753
11	Kerman	2003-2008, 2014	$y=-471497+236.1x$	0.961	45992
12	Hamadan	2003-2007, 2009	$y=-427310+214.3x$	0.969	39938
13	Lorestan	2003, 2005-2007, 2009	$y=-361353+180.8x$	0.979	33741
14	Kurdistan	2003, 2005-2007, 2009	$y=-331185+165.8x$	0.980	31881
15	Golestan	2003-2009, 2014	$y=-267439+134x$	0.944	26824
16	Yazd	2004-2007, 2009, 2014	$y=-236001+119.7x$	0.932	23616
17	Zanjan	2003-2007, 2014	$y=-221498+110.9x$	0.977	22614
18	Ardabil	2003, 2005, 2007, 2009, 2014	$y=-221498+110.9x$	0.961	21389
19	Kermanshah	2003-2006, 2014	$y=-152285+76.77x$	0.969	20059
20	Markazi	2003-2008, 2014	$y=-196760+98.6x$	0.930	19927
21	Sistan and Baluchestan	2003-2009, 2014	$y=-195227+97.67x$	0.963	18117
22	Qom	2003, 2005-2008	$y=-170805+85.57x$	0.974	17048
23	Qazvin	2003-2008, 2014	$y=-137502+69.11x$	0.968	15995
24	Hormozgan	2003,2005-2008, 2014	$y=-160212+80.17x$	0.921	15062
25	Bushehr	2003-2009, 2014	$y=-150301+75.23x$	0.960	14307
26	North Khorasan	2005, 2007-2009, 2014	$y=-136643+68.4x$	0.936	13076
27	South Khorasan	2006-2009, 2014	$y=-148690+74.3x$	0.937	12912

No.	Province	Data gathering period	The fitted simple linear regression model	R^2_{adj}	Number of cancer
28	Semnan	2003-2007,2009, 2014	$y=-134433+67.29x$	0.982	12843
29	Chaharmahal and Bakhtiari	2005-2009, 2014	$y=-88302+44.39x$	0.947	10374
30	Kohgiluyeh and Boyer-Ahmad	2005-2009, 2014	$y=-99358+49.76x$	0.908	9756
31	Ilam	2004, 2006-2008, 2014	$y=-51959+26.11x$	0.961	6005

It is noticeable that various sets of periods are mentioned for data gathering to gain the best simple linear regression under the best determination coefficient in each province. Therefore, the period of data gathering in one province may differ from another one. The fitted simple linear regression for each province is used to forecast the annual cancer new cases by 2040. It is supposed that the average survival duration of each cancer patient after cancer occurrence is five years. It is supposed that 20 percent of cancer new cases in each province in any year will die per year until the next five years after it. For example, the number of cancer patients in 2040 is the summation of new cancer cases in 2040, 80 percent of cancer new cases in 2039, 60 percent of cancer new cases in 2038, 40 percent of cancer new cases in 2037, and 20 percent of cancer new cases in 2036.

Iran has 31 provinces, and it is obvious that the number of demand regions and candidate regions is 31. The time of vision is considered the year 2040. The location-allocation problem is going to be solved by using information forecasted for the year 2040. The future value of all cost items of the year 2040 is calculated by using an annual interest rate of 0.2 (Table 3). Not all provinces need to be a possible destination for each province's patients owing to the far distance between them. Table 2 gives the possible destinations for patients of each province, the weight of each province in therapeutic justice, the cost of providing one cancer specialized bed in each province in 2040(cv), and traveling cost of each cancer patient to each possible destination (c) in 2040 (Table 2, all cost items are based on USD).

Table 3. Possible neighbor destinations and cost parameters in 2040

i, j	Demand Region	cv_j	Possible Destination (i, c_{ij})
1	Markazi	4246626	Markazi(1,0) , Isfahan(4,18), Tehran(12,18), Qom(23,16)
2	Ardabil	4246626	Ardabil(2,0), East Azerbaijan(11,18)
3	West Azerbaijan	4246626	West Azerbaijan(3,0), East Azerbaijan(11,18)
4	Isfahan	5308283	Isfahan(4,0)
5	Khuzestan	4246626	Khuzestan(5,0)
6	Ilam	3538855	Ilam(6,0), Khuzestan(5,16), Lorestan(13,16), Kermanshah(25,14)
7	North Khorasan	3538855	North Khorasan (7,0), Razavi Khorasan(27,18)
8	Bushehr	3538855	Bushehr (8,0), Fars(21,18)
9	Hormozgan	3538855	Hormozgan(9,0), Kerman(24,16)
10	South Khorasan	3538855	South Khorasan (10,0), Razavi Khorasan(27,18)
11	East Azerbaijan	5308283	East Azerbaijan(11,0)
12	Tehran	5308283	Tehran(12,0)
13	Lorestan	4246626	Lorestan(13,0)
14	Gilan	4246626	Gilan(14,0), Qazvin(22,16)
15	Sistan and Baluchestan	3538855	Sistan and Baluchestan(15,0), Kerman(24,16)
16	Zanjan	4246626	Zanjan(16,0), Qazvin(22,16)

i, j	Demand Region	cv_j	Possible Destination (i, c_{ij})
17	Mazandaran	4246626	Mazandaran(17,0)
18	Semnan	3538855	Semnan (18,0), Tehran(12,18)
19	Kurdistan	3538855	Kurdistan(19,0), Kermanshah(25,14), Hamadan(28,16)
20	Chaharmahal and Bakhtiari	3538855	Chaharmahal and Bakhtiari(20,0), Isfahan(4,18)
21	Fars	5308283	Fars(21,0)
22	Qazvin	4246626	Qazvin(22,0)
23	Qom	4246626	Qom(23,0)
24	Kerman	4246626	Kerman(24,0)
25	Kermanshah	3538855	Kermanshah(25,0), Kurdistan(19,14), Hamadan(28,16)
26	Golestan	3538855	Golestan(26,0), Mazandaran(17,16)
27	Razavi Khorasan	5308283	Razavi Khorasan(27,0)
28	Hamadan	4246626	Hamadan(28,0)
29	Kohgiluyeh and Boyer-Ahmad	3538855	Kohgiluyeh and Boyer-Ahmad (29,0), Khuzestan(5,16), Fars(21,18)
30	Yazd	4246626	Yazd(30,0)
31	Alborz	5308283	Alborz(31,0)

The annual consumption coefficient per bed in a cancer hospital for each cancer patient is supposed to be equal to 0.02. The maximum allowed cancer patient allocating to foreign provinces is supposed to equal 14500 persons, and the minimum acceptable bed capacity in each province is considered 250 beds. Three scenarios considered as cancer hospitals' bed capacity are 300-bedded, 500-bedded, and 1000-bedded.

Transforming the multi-objective model into a single-objective model: The proposed bi-objective model can be transformed into a single objective model by using the optimality grade approach. For this, first, we solve two single objective models (min and max) for each objective function, four models for all, to reach the maximum value (Z^u) and the minimum value(Z^l) of each objective function. Four models are solved by using the CPLEX solver of GAMS 24.1.2 software, and the optimum values are reported in Table 4.

Table 4. The optimum values of objective functions

Objective function	Optimum direction	Optimum value
Z_1	max	$Z_1^u = 1391800000000$
	min	$Z_1^l = 153593000000$
Z_2	max	$Z_2^u = 295933$
	min	$Z_2^l = 333$

The bi-objective model is transformed into a single objective model as below:

$$\max \quad \lambda$$

s.t:

$$\lambda(Z_1^u - Z_1^l) \leq Z_1^u - \left(\sum_{i=1}^{N}\sum_{j=1}^{N} c_{ij} d_{ij} Q_{ij} + \sum_{j=1}^{N}\sum_{s=1}^{S} cv_j bc_s M_{sj}\right)$$

$$\lambda(Z_2^u - Z_2^l) \leq Z_2^u - \sum_{j=1}^{N}\left(\sum_{s=1}^{S} bc_s M_{sj} - V_j\right)$$

$$\sum_{j=1}^{N} Q_{ij} = de_i \quad \forall i = 1,\dots,N$$

$$V_j = \alpha \times \sum_{i=1}^{N} Q_{ij} \quad \forall j = 1,\dots,N$$

$$\sum_{i=1}^{N} Q_{ij} \le M \times Y_j \quad \forall j = 1,\dots,N$$

$$\sum_{j=1}^{N} a_{ij} Y_j \ge 1 \quad \forall i = 1,\dots,N$$

$$Y_j \le \sum_{i=1}^{N} Q_{ij} \quad \forall j = 1,\dots,N$$

$$Q_{ij} \le a_{ij} \times \max_{ij}$$
$$\forall i = 1,\dots,N;\ j = 1,\dots,N;\ i \ne j$$

$$V_j \ge \min_j \times Y_j \quad \forall j = 1,\dots,N$$

$$V_j \le \sum_{s=1}^{S} bc_s M_{sj} \quad \forall j = 1,\dots,N$$

$$M_{Sj} \le u_s Y_j \quad \forall j = 1,\dots,N;\ s = 1,2,\dots,S$$

$$Q_{ij}, V_j \ge 0; Y_j \in \{0,1\}; M_{sj} \in N; 0 \le \lambda \le 1$$
$$\forall i = 1,\dots,N;\ j = 1,\dots,N;\ s = 1,2,\dots,S$$

Final single objective model solving results: The final single objective model is solved by using the CPLEX solver of GMAS 24.1.2. The optimum value of λ is 0.99517. The results indicate that 26 provinces are selected to locate at least one cancer hospital there. All needed bed capacity in each selected province and details of allocation are shown in Table 5.

Table 5. Results of final single model solving

i, j	Provinces	V_j	Allocated provinces (i, Q_{ij})	M_{1j}	M_{2j}	M_{3j}
1	Markazi	0	…..	0	0	0
2	Ardabil	300	Ardabil(2,15000)	1	0	0
3	West Azerbaijan	1100	West Azerbaijan(3,55000)	2	1	0
4	Isfahan	2400	Isfahan (4,105134), Chaharmahal and Bakhtiari(20,10374), Markazi(1,4492)	3	1	1
5	Khuzestan	2393	Khuzestan(5,111505), Kohgiluyeh and Boyer-Ahmad(29,8149)	0	1	2
6	Ilam	0	…..	0	0	0
7	North Khorasan	0	…..	0	0	0
8	Bushehr	286	Bushehr(8,14307)	1	0	0
9	Hormozgan	300	Hormozgan(9,15000)	1	0	0
10	South Khorasan	258	South Khorasan(10,12912)	1	0	0
11	East Azerbaijan	3028	East Azerbaijan(11,143723), Ardabil(2,6389), West Azerbaijan(3,1306)	2	1	2
12	Tehran	5777	Tehran(12,276451), Markazi(1,12396)	1	1	5
13	Lorestan	795	Lorestan(13,33741), Ilam(6,6005)	1	1	0
14	Guilan	1490	Guilan(14,74511)	0	1	1
15	Sistan and Baluchestan	300	Sistan and Baluchestan(15,15000)	1	0	0
16	Zanjan	300	Zanjan(16,15000)	1	0	0
17	Mazandaran	1072	Mazandaran(17,51753), Golestan(26,1824)	2	1	0
18	Semnan	257	Semnan(18,12843)	1	0	0
19	Kurdistan	600	Kurdistan(19,30000)	2	0	0
20	Chaharmahal and Bakhtiari	0	…..	0	0	0
21	Fars	1600	Fars(21,78393), Kohgiluyeh and Boyer-Ahmad(29,1607)	2	0	1
22	Qazvin	472	Qazvin(22,15995), Zanjan(16,7614)	0	1	0
23	Qom	341	Qom(23,17048)	0	1	0
24	Kerman	983	Kerman(24,45992), Hormozgan(9,62), Sistan and Baluchestan(15,3117)	0	0	1
25	Kermanshah	438	Kermanshah(25,20059), Kurdistan(19,1881)	0	1	0

i, j	**Provinces**	V_j	**Allocated provinces** (i, Q_{ij})	M_{1j}	M_{2j}	M_{3j}
26	Golestan	500	Golestan(26,25000)	0	1	0
27	Razavi Khorasan	3104	Razavi Khorasan(27,142104), North Khorasan(7,13076)	3	0	2
28	Hamadan	799	Hamadan(28,39938)	1	1	0
29	Kohgiluyeh and Boyer-Ahmad	0	…..	0	0	0
30	Yazd	472	Yazd(30,23616)	0	1	0
31	Alborz	2300	Alborz(31,111961), Markazi(1,3039)	1	0	2

Five provinces consisting Markazi, Chaharmahal and Bakhtiari, Ilam, Kohgiluyeh and Boyer-Ahmad, and North Khorasan are, three red colored provinces in figure 3, are not selected to construct at least one cancer hospital even in the lowest capacity. Consequently, the cancer patients of these provinces are allocated to at least one other neighbor province. For instance, Lorestan is the only destination of all cancer patients of Ilam, whereas the cancer patients of Kohgiluyeh and Boyer-Ahmadare are allocated to two destinations as Fars and Khuzestan. Some provinces have the role of destination for cancer patients of neighbor provinces. For example, Isfahan receives from both of Markazi, and Chaharmahal and Bakhtiari. There are some provinces that, although they are selected to construct at least one cancer hospital, a proportion of these provinces' cancer patients are allocated to another destination. For example, Sistan and Baluchestan will have a 300-bedded cancer hospital, but moreover gives 3117 cancer patients to Kerman, simultaneously. Figure 4 represents the traveling map of cancer patients based on the results of the proposed models for Iran in 2040.

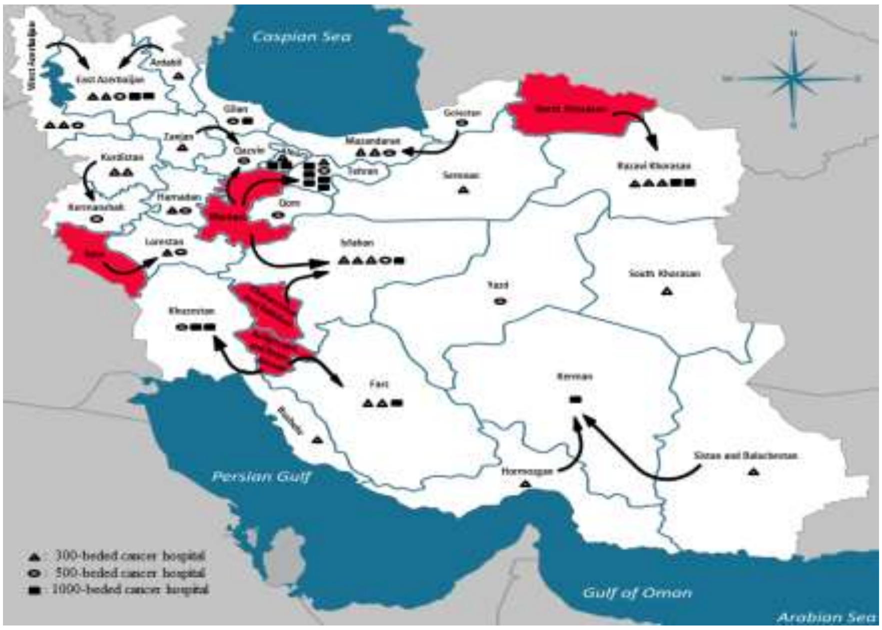

Figure 4. located cancer hospitals and allocated destinations (Plan for 2040).

Conclusion

This paper proposed a mixed-integer mathematical model to achieve an economic-efficiency objective in cancer hospitals' location-allocation problem. For the first time, the bed efficiency of the hospital was mentioned for hospital location and capacitation modeling. To solve the model in the case of Iran in 2040, the annual new cancer incidences until 2040 were forecasted by simple linear regression that not be occurred before. The proposed bi-objective model transformed into a single objective model by using the optimality grade approach. Twenty-six provinces are selected to construct at least one cancer hospital there, and all cancer patients are allocated to at least one destination.

In future researches, the capability of general hospitals and clinics can be used as suppliers of cancer hospitals. Modifying the model to make decisions about specialized human resources and specialized requirements allocation is recommended too. Considering multi-period models can propose a time-based plan for constructing cancer hospitals step by step until a specific time, such as 2040. Moreover, the cancer hospitals' location-allocation can be noticed more detailed at the town level instead of the province level to reach a more efficient location and allocation. There may be some demand for cancer curing services from overseas. Foreign customers' demand can be considered in the model. The value of the parameters as demands or costs are estimated for the future (2040) and consequently may be uncertain items; and Therefore, it is suggested to use an uncertainty approach such as fuzzy theory or robust optimization to deal with uncertainty. Most of the five provinces that are not selected to construct at least one cancer hospital are considered undeveloped provinces in Iran. Modifying the model to reach therapeutic justice can be noticed in future researches.

Competing Interests

The authors declare no competing interests

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