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Developing an imperialist competitive algorithm based on two improvement strategies in a hierarchical capacitated health network

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Abstract

The present paper on the location of clinic (C), hospital (H) and medical center (MC) in the Golestan province of Iran is motivated by its present condition coming from limited distribution and ease of access for related Cs, Hs, and MCs. Design of a median hierarchical location-allocation model for the needed healthcare facilities, from Cs to Hs and MCs, is a vital and valuable activity from the emergency viewpoints of both patients and the government. This model has been formulated as a mixed-integer linear mathematical framework for finding the optimal location of these capacitated healthcare facilities, the allocation of patients to these Cs, Hs, or MCs and also for the referrals of the patients' needs to them while minimizing the total demand-weighted travel distance. This problem is in the category of an *NP*-hard problem. An efficient and robust imperialist competitive algorithm based on two initialization and local mechanisms is also presented to improve the computational time and accuracy of simulation results. Comparative performance of the developed method with some well-known metaheuristics has been surveyed using a real case study for the healthcare network for different problems with a change in the model parameters' values. The novel method is reliable and valid according to accuracy and execution time. The sensitivity analysis results concerning the maximum number of locations (i.e., Cs, Hs and MCs). Furthermore, the percent of the referred demand determines the significance and practical observations related to the combination of the Cs, Hs, and MCs to be established. Our new model is illustrated to be gainful as it offers a robust build plan to designers for making location decisions for developing the Golestan healthcare network.

Keywords Health network · Three-level hierarchical model · Median location and allocation · Mixed-integer linear programming · Imperialist competitive algorithm

1 Introduction

During the last decades, the concept of location in the healthcare network has been widely developed by many researchers to reducing the undesirable effects on the quality of social life and economic conditions. Many planners are still improving the healthcare network by studying practical components of their network through considering actual data, such as healthcare facilities, types of healthcare services, capacity, and referral services. So, they must design models to address this information that impacts the healthcare network.

On the other hand, many facility networks are hierarchical in nature. These facilities are normally hierarchical concerning the types of services they obtain. For instance, the healthcare network includes of clinics (Cs), hospitals (Hs) and medical centers (MCs). In this network, an C obtains primary healthcare (PH) and diagnostic service (DS). An H obtains outpatient surgery (OS) in addition to those obtained by an C; and an MC obtains OS and inpatient service (IS). As another instance of a hierarchical network, consider a solid waste disposal network. The solid waste is collected from the source of solid waste and

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shipped to transfer stations or landfill stations by trucks. Other instances of a hierarchical network are: education system, postal system, banking system, search and rescue system, and production–distribution system. This concept is a novel plan for healthcare network modeling to deal with hierarchical challenges and healthcare service efficiency.

Also, the capacity and referral concepts in designing a healthcare network make it vital to Iran's Ministry of Health and Medical Education (MHME) to determine patients' demand and the final consumption of healthcare services (i.e., the share of total health spending). In this way, the capacitated referral network is one of the efficient and extensively used methods in accessing healthcare services utilized in this work. This model's characteristics make it possible to analyze the situation of complex healthcare networks and lead to an extensive understanding of the accessibility, quality, and efficiency of the health system. Thus, in this paper, the criteria to satisfy patients' demands for healthcare services are determined using a capacitated referral network to be introduced in the mathematical model as parameters explained later in detail.

Our model was inspired by a real case study of selecting the suitable locations of Cs, Hs, and MCs and allocating the services to the patients; however, a comprehensive modeling framework has been developed because numerous healthcare experience similar problems. The issue is that patients go to health facilities to treat disease, and existing health facilities must provide the services that patients want. On the other hand, patients should receive health services PH from the nearest Cs, Hs, or MCs, whichever is opened/installed (output of the novel mathematical model with minimum demand-weighted distance). By locating new C, H, and MC, healthcare designers serve patients' needs based on health facilities' capacity. The healthcare services in the health facilities are served to the patients. During this time, some patients may be unsatisfied with their demands, so they might be referred from a lower level to a higher-level health facility to receive another healthcare service.

On inclusivity and exclusivity concepts, the Hs and Cs tend to be associated with inclusivity since Hs serve all healthcare services offered by Cs and one additional service called OS. However, MCs and Cs show an entire hierarchy since the services provided by MCs are not provided by Cs and vice versa. Lastly, the relationship between MCs and Hs is neither inclusive nor exclusive.

This paper focuses on the location of C, H, and MC in a hierarchical healthcare network. All patients must first be examined by a doctor at a C for temperature, heart rate, blood pressure, and breathing rate before receiving care at either an H or an MC. So, all PHs and DSs are located at the Cs. It is assumed that the DSs are performed in the nearest Cs, and there is no need to refer the patient to the H. Based on that, to deal with this problem, in reality, we chose the healthcare network in the Golestan province of Iran as the case study of this research. The healthcare industry is growing in the Golestan province, comprising physicians, Cs, Hs, and MCs expected to increase yearly due to the spread of diseases and patients' needs. This growth in patients' total demand for care shows how the actions of these health service locations can affect a country's economy, health, and development.

We introduce a new mixed-integer linear mathematical model to design an efficient healthcare network by minimizing the total travel distance between patients and installed Cs, Hs, and MCs. For the first time, this work considered the location of Cs, Hs, and MCs simultaneously to decrease the capacity shortage that may occur during the service to patients with existing ones in the healthcare network. The novel mathematical model is denoted as a three-level hierarchical capacitated problem. While this problem is a generalized classical location problem, it is Non-deterministic-polynomial (*NP*)-hard. So, the computational complexity of a realistic case study and significant instances of this problem must deal with metaheuristic algorithms. Therefore, effective solution methodologies such as metaheuristic algorithms must be executed to provide the solution for the new location model. Binary genetic algorithm (BGA), binary imperialist competitive algorithm (BICA), and binary particle swarm optimization (BPSO) can be utilized for solving instances of designed healthcare networks and increasing the quality of solutions concerning the accuracy and running time. Then, a case study on the actual healthcare network with some test examples is suggested to show the validity and acceptability of the novel mathematical representation and the influence of the developed approaches.

According to these issues, we are searching for solutions to the following questions:

- Which Cs will be established to serve patients with PH and DSs and refer them to Hs or MCs?
- Which Hs will be established to serve PH, DSs, and OSs to patients and refer them to the MCs?
- Which MCs will be established to serve OSs and ISs to the patients?
- What would be the total distance between patients and the nearest Cs after opening new Cs?
- What would be the total distance between patients and the nearest H after opening new Hs?
- What would be the distance between Cs and Hs for referred patients after opening new Cs and Hs?
- What would be the distance between Cs and MCs for referred patients after opening new Cs and MCs?

- What would be the distance between Hs and MCs for referred patients after opening new Hs and MCs?

The remainder of this study is structured as follows. A brief review of the literature is summarized in Sect. 2. The mathematical programming formulation of the problem is given in Sect. 3. Various approaches to solving the problem are described in Sect. 4. Section 5 describes a real case study by considering the Golestan healthcare network system in one of Iran's provinces. Section 5.3 demonstrates the results of computational experiments and performance analysis of the median hierarchical healthcare location-allocation problem for the case study. Finally, in Sect. 6, the study is concluded and some recommendations are given for future research work.

2 Literature review

Numerous investigators and systems scientists have addressed facility location and allocation problems over the last few decades. The first paper was from Weber [1], which introduced warehouse location and allocation problems to minimize the total distance between the warehouse and clients. Subsequent studies have been considered in formulating various location and allocation models. The median was a class of location-allocation models whose goal was to determine the optimal locations for facilities to serve clients to minimize the total distances between each client and his/her nearest facility [2, 3]. Coverage models compose another category of location-allocation models. Coverage models search to locate facilities so that every client is served within a given coverage radius [4, 5]. The aim of the hierarchical problem was the location of multi-level facilities. However, the facilities cover the maximum population according to specific restrictions on the number of facilities. When a hierarchical model is considered, the facilities are classified as exclusive or inclusive depending on whether higher-level facilities can satisfy customer needs for both higher- and lower-level services. In contrast, lower-level facilities can only do so for lower-level services [6, 7]. The idea of the fixed cost location problem was to choose the appropriate locations to install facilities and the flow between facilities and clients. The objective was to minimize the total transportation and fixed cost for installing facilities [8, 9]. There are many papers on location-allocation problems in modeling healthcare systems. The following two subsections discuss more information about the health network and past papers concerning healthcare facility location-allocation.

2.1 Health network background

We study the concept of a health network concerning public health services in the Golestan province of Iran, access to the point of care resource invested by the private sector, and the government's role in designing healthcare requirements. This is the case of the Mazanderani (Tabari), Turkic, Sistani, Baloch, Qizilbash, Azeris, Kazakhs, Kurds, Armenians, and Georgians peoples. With a public health service-based system, the health officials in Golestan province have one of their main goals to provide parity among the province's residents, regardless of their socio-economic standing or geographic distribution. The accessibility of health facilities in healthcare delivery with minimum distance is a significant objective. Cs, Hs, and MCs provide healthcare services in these networks. Health facilities provide four main types of services: PH, DSs, OSs, and ISs.

PH is the first level of contact for patients with the local health network. It states the leading health problems in a county of cities and rural populations, providing health promotion, preventive, curative, and rehabilitative services. Family physicians, internists, geriatricians, pediatricians, obstetrician–gynecologists, nurse practitioners, or physician assistants at Cs and Hs are the first point of contact for the health network as a PH provider. PH includes treatment of a health condition, support in managing long-term healthcare, seeing health professionals help you maintain good health with regular health checks, health advice when you have concerns, disease prevention and screenings, and support for ongoing care.

Diagnosis is specifying the nature of a disease or disorder and detecting it from other possible statuses. DSs signify services served to patients with particular demands that will help their recovery, such as training, psychometric, psychological, and medical tests. Medical tests and processes utilized to provide health information and diagnose pathological and no pathological statuses of the human body include cellular and chemical analysis, diagnostic imaging, genetic testing, measurement, and physical and visual examination.

The doctors may recognize the surgery as a way to improve your condition upon diagnosis. This decision is made according to the evaluation of the patient's medical history and medical tests, such as blood tests, X-rays, magnetic resonance imaging, computed tomography scan, electrocardiogram, or other laboratory work implemented to specify the exact diagnosis. A patient has two surgery options subject to the diagnosis:

1. OS
2. IS

OS, also known as same day or ambulatory surgery, occurs when the patient is expected to return to the house the same day after the surgery and does not need an overnight stay at the H or MC. OS is becoming progressively possible due to progress in painkillers, pain management, and surgical methods. The term OS results from the fact that surgery patients may arrive and quit the H or MC on the same day. The scheduled time of discharge depends on the type of surgery, the anesthesia used, insurance coverage, and the policy of the H or MC. In general, most patients go home between 1 and 4 h after OS. Patients who undergo an OS should have someone to drive them home and stay with them following the procedure. Most patients are restricted from driving for at least 24 h after OS. Patients often experience drowsiness and minor after effects. These involve muscle aches, sore throat, and occasional dizziness and headaches. Infrequently, nausea may also be present. There may also be fatigue and discomfort for a day or two following the OS. This discomfort differs depending on the type of OS performed.

Patients' doctor will give them a list of instructions before their OS. They are likely to include:

- *Don't eat or drink*. Patients will probably have to fast (not eat or drink anything) for a certain number of hours before their procedure.
- *Bring a support person*. Patients may feel groggy after surgery, so a support person can help listen to their doctor's instructions and ask any questions. Their friend or family member will also need to drive them home.
- *Wear loose, comfortable clothes*. After their surgery, patients may have a bandage that will interfere with tight jeans or other snug clothing. They may also be sore from the surgery, so keep all clothing oversized and comfortable.

The most common OS types are:

- *Cataract surgery*. A cataract happens when your eye's natural lens becomes cloudy. During the outpatient procedure, doctors remove your natural lens and replace it with an artificial lens.
- *Ear/nose/throat surgery*, including removal of tonsils and adenoids.
- *Cosmetic surgeries*, including breast reconstruction and skin grafts.
- *Urologic procedures*, including vasectomy.
- *Orthopedic procedures*, including knee and hip replacements, as well as toe, foot, ankle, and leg procedures.
- *Gall bladder removal*.
- *Skin procedures*, including mole removal and other skin repairs.
- *Lumpectomy*, which is the removal of a cancerous tumor in the breast.
- *Colonoscopy and endoscopy*.
- *Hand, wrist, elbow, and ankle repairs*, including procedures on people with arthritis.
- *Tendon and muscle repair*, including rotator cuff surgery.
- *Gynecological procedures*, such as D&C and tubal ligation.
- *Hemodialysis* for those with kidney disease.
- *Hernia operations*.
- *Hemorrhoid* procedures.
- *Kidney stone* treatment.

Before patients are sent home, the nurse will go over their discharge instructions with them and their family/friend. The goal is to teach them what patients will need to do when they are home. The nurse will go over the following with patients:

- Activities patients can do
- What patients are allowed to eat
- How to help manage their pain
- When patients should see their doctor again
- How to take care of their wound/stitches
- Anything special related to the procedure they had done
- The medicine they are taking
- It is very important that they ask questions and are familiar with how to care for theirself once they leave.

IS is any surgery where the patient needs to remain overnight or longer after the surgery is completed, for care or observation. In general, ISs with larger incisions are more likely to require an overnight stay or even an extended stay in the MC. This would include procedures like open-heart surgery, brain surgery, major abdominal surgery, joint replacements, and lung procedures. Minimally invasive procedures and procedures that have short recovery periods, such as carpal tunnel release and short cosmetic surgeries would be more likely to be OSs. Indeed, IS occurs when a surgical activity is executed with the hope that the patient stays in the MC for one or more nights. For post-surgical recovery needs, IS patients rest at the MC for at least one night after their surgery. IS patients need to have pertinent legal forms on hand such as the Advanced Directive, Living Will, and/or Power of Attorney. They should also bring a change of comfortable clothing and eyeglasses, a walker, or other necessary assistive medical devices. Valuables should stay at home. Nurses help hospitalized patients follow the diet, activity, and medication regimen prescribed by the surgeon. Before going home from an IS, nurses review home-care instructions including medications, bandages, activity restrictions, and required follow-up appointments.

At MCs, healthcare professionals perform ISs in the following areas of medicine:

- Childbirth
- Stroke treatment
- Heart attack treatment
- Hip fracture
- Respiratory failure
- Septicemia
- Rehabilitation therapy
- Cardiac surgeries and procedures
- General surgery,
- Urology/andrology,
- Abdominal surgery,
- Gynecology,
- Proctology,
- Ophthalmology,
- Vascular surgery / phlebology,
- Otolaryngology,
- Traumatology / orthopedics,
- Gastroenterology,
- Plastic and bariatric surgery.

Any IS procedure assumes that the patient will stay in the MC. The elapsed time spent under medical observation is determined by the scope and complication of surgery, the patient's public health, and many other components. Patients are admitted for medical disorders that need appropriate care and treatment between a few hours to several days in the IS department of an MC. An IS department of the MC is made ready with beds, medical equipment, and clock availability of healthcare professionals and nurses [10–13].

The advantages of OS over IS are as follows:

- *Convenience*: The convenience of recovering in the home normally makes recovery time more comfortable than staying in an H.
- *Lower cost*: Since there are no room cost, and related costs, charges are much lower for OS.
- *Reduced stress*: OS is less stressful than IS. This is chiefly true for children who are scary to stay away from home.
- *Scheduling is more predictable*: In an H setting, ISs that take longer than expected can delay scheduled surgeries. An OS setting can normally stay within a set schedule since the process are less complex and more routine.

The differences between OS and IS include:

- *Stay*: The patient is expected to return to the home the same day after the surgery; whereas, the patient will stay overnight or longer in the MC for an IS,
- *Cost*: Costs are physician fee plus procedure for OS; whereas, costs are varies, based on stay and procedures for IS,
- *Care*: The patient monitored until released for OS; whereas, the patient monitored until 24-h for IS,
- *Procedure type*: OS procedures include imaging, lab tests, minor surgeries; whereas, IS procedures include major or emergency surgeries, unstable health conditions.

Last, implementing a patient decision aid to communicate on the C, H simultaneously, and MC location, services, referral, and related capacities satisfies the requirements of healthcare designers in nations with national health systems, and Golestan province planners in particular.

2.2 Healthcare facility location-allocation models

One of the most practical uses for facility location problems is in the field of healthcare networks. Cs, Hs, and MCs may be a part of such networks. These sites' planned networks comprise many health services organized in a hierarchy, which will be depicted in better depth later. So, location analysis must enhance both the interactions between designers and the movement of patients through healthcare facilities. Based on the currently available literature, we affirm the value of other location models for healthcare network design. However, we address the review of hierarchical problems that particularly relate to our work's aims and are significant in the framework of healthcare networks.

The facility location problems were developed through mathematical formulation composed of objective values and restrictions subject to detected spatial features. One of the broad applications of border health services management in developing countries was focusing on the location of healthcare facilities. According to this definition, location-allocation models can be favorably employed to design healthcare systems. One of the first works was via Gould and Leinbach [14], who studied the location of Hs and the determination of their capacities in Western Guatemala. So, location problems had obtained favorability in healthcare literature [15, 16] markedly. Thereupon, the literature focuses on some location factors.

Applicable criteria most generally considered in the literature on healthcare facility location are as follows:

- *Minimize travel costs for patients*: This objective can be determined as the demand-weighted distance between a population area of patients and selected locations. The p-median model was widely applied for locating a set of health service providers and allocating patients' needs to them with this objective [17–20].
- *Maximize covered patients' demands*: A cover problem considers that a population area is covered only if it can

be assigned to a C, H, or MC within a given maximum distance, and the aim is to maximize the covered population area of patients. Coverage models search to locate Cs, Hs, and MCs so that every population area of patients is covered within a definite standard level [20–24].

- *Maximize equity of access to medical services*: The equity signifies that healthcare services are accessible based on patients' demands rather than on geographical location or financial ability. Equal access for equal demand needs situations by which those with equal demands had equal *chances* to access medical services, and, as an inference, those with unequal demands had accordingly unequal chances to access medical services [25–27].

  For example:

  - Equal access to medical services for those in equal demand of medical services;
  - Equal usage of medical services for those in equal demand of medical services;
  - Similar health results.

- *Capacity planning in a healthcare facility*: Capacity planning is the state of finding the capacity of health facilities needed by a healthcare network to satisfy patients' demands for its medical services. The modeling of capacity decisions was developed with a resource-based view of Cs, Hs, and MCs. For instance, the capacity of Cs is evaluated by the number of general practitioners or primary care physicians assigned to that C. Furthermore, the number of beds was a significant factor in H capacity. Also, the number of medical professionals specified the MC's capacity. In this situation, there were constraints on the number of patients assigned to a C, H, and MC [21–25].
- *Assumptions on health facility types and patient flow*: In most countries, healthcare networks are designed in hierarchical frameworks. There were various health facilities, such as Cs, Hs, and MCs. Also, there was a hierarchy in the medical services provided by these facilities. For example, an H can offer PH, and DSs provided in an C. Furthermore, some health networks needed a referral from a primary care physician before a patient could seek OS or IS at an H or MC, respectively. Hierarchical location models can include such attributes [28–34].

2.3 Gaps in the literature and novelty in research

Based on the literature review, abundance gaps have been revealed in Table 1.

- It is perceived that many research papers had modeled healthcare problems as a p-median and maximum covering location. These models will not be suitable for the healthcare problem being designed in our study due to the need for four health service categories at the three healthcare facility levels. The allocation-location model developed in our research does not have this topic. So, the hierarchical healthcare network was a preferable model to satisfy the need for four categories of health services with three levels of health facilities.
- No paper was available at the location of healthcare facility types, such that accessibility issue was considered concerning minimum service distance for patients to their nearest health service providers for both referral and non-referral cases. Accessibility to health facilities was related to the ability of a government to provide a set of healthcare services. Accessibility topics studied by the authors are confined to only referral services and public health networks. Minimum service distance was a crucial criterion, especially for Cs and Hs in the Golestan province of Iran. From the viewpoint of medical health officers, the senior government officials of a health department in Golestan province had obtained guidance for the availability of healthcare facilities on minimal distance for referral and non-referral cases. Attention to the service distance criterion helped health service providers access related healthcare services. The developed model considered the accessibility criterion by combining constraints on establishing locations with the shortest distance between the patients and health service provider facilities for referral and non-referral services.
- Some researchers have considered the issue of referral for health networks. They studied referral only from mid-level to high-level healthcare facilities [30, 31]. However, to our knowledge, only Chouksey et al. [29] added referrals from the first to second and third levels into a health facility location problem with a fixed cost. Considering the patients' demands and practice in the Golestan province of Iran, the new model also addressed referrals from the Cs to Hs, Cs to MCs, and Hs to MCs. The new problem was modeled as a median hierarchical health facility location-allocation problem.
- Few works endeavored to develop metaheuristic methods to solve the healthcare location-allocation problems computationally effectually. This study proposed an efficient metaheuristic to be executed to solve the novel problem in less computational time than other metaheuristic algorithms. The focal point of the new paper was the design of a model for

Table 1 Review of the relevant studies

References	Problem type				Capacitated	Referral	Flow type		Metaheuristic approach	Case study
	Median	Hierarchical	Coverage	Fixed			Single-	Multi-		
Jia et al. [17]	✔	×	×	×	✔	×	✔	×	✔	China
Murad et al. [18]	✔	×	×	×	×	×	✔	×	×	Saudi Arabia
Özceylan et al. [19]	✔	×	×	×	×	×	✔	×	×	Turkey
Tao et al. [20]	✔	×	×	×	×	×	✔	×	×	China
Ye and Kim [21]	×	×	✔	×	✔	×	✔	×	×	USA
ElKady and Abdelsalam [22]	×	×	✔	×	✔	×	✔	×	✔	×
Shariff et al. [23]	×	×	✔	×	✔		✔	×	✔	Malaysia
Guerriero et al. [24]	×	×	✔	×	✔	×	✔	×	×	Italy
Khodaparasti et al. [25]	×	×	✔	×	✔	×	✔	×	×	Iran
Delgado et al. [26]	×	×	✔	×	×	×	✔	×	×	World Health Organization
Pourrezaie-Khaligh et al. [27]	×	×	✔	×	✔	×	✔	×	✔	Iran
Baray and Cliquet [28]	✔	✔	✔	×	×	×	×	✔	×	France
Chouksey et al. [29]	×	✔	×	✔	✔	✔	×	✔	×	India
Galvao et al. [30]	✔	✔	×	×	×	✔	×	✔	✔	Brazil
Galvão et al. [31]	✔	✔	×	×	✔	✔	×	✔	✔	Brazil
Maleki Rastaghi et al. [32]	×	✔	×	✔	✔	✔	×	✔	×	Iran
Mestre et al. [33]	×	✔	✔	×	✔	✔	×	✔	×	Portugal
Zarrinpoor et al. [34]	✔	✔	×	×	✔	✔	×	✔	×	Iran
This study	✔	✔	×	×	✔	✔	×	✔	✔	Iran

locating healthcare facilities in the Golestan province of Iran. The different values of problem parameters can also assist the designers in finding out the effect on the performance of the healthcare network.

- The novel median hierarchical facility location-allocation model for healthcare networks was introduced to plan health facilities for the Golestan province in Iran.
- As reported in the review literature and Table 1, many exact and metaheuristic methods exist to solve the health facility location problem. However, none of them had implemented the imperialist competitive algorithm (ICA) as a solution approach to solve the novel model. In this study, we want to execute an improved ICA to solve the problem efficiently.

3 Problem description

3.1 Hierarchical healthcare network

General healthcare facilities are a three-level hierarchical network in the Golestan province of Iran, consisting of Cs, Hs, and MCs from the lowest to the highest level [35]. PH and DSs are provided by Cs. Indeed, most medical treatments and cures should be performed at Cs. Hs provide PH, DSs, and OSs. OSs and ISs are essentially organized in MCs. Referrals between various health facilities are vital and fundamental for operating a three-level hierarchical healthcare network.

The hierarchical facilities can be categorized into single-flow versus multi-flow, nested versus non-nested, or spatially coherent versus non-coherent networks [36]. Considering the three-level health facilities, in a single-flow network, patients must be examined by a physician at Cs to receive PH and DSs and then transferred to Hs or MCs if needed. On the contrary, patients can select health facilities at any level of the first visit in a multi-flow network. In a nested network, Hs can also supply PH and DSs. In contrast, in a non-nested network, Cs and Hs satisfy mutually exclusive health services, and PH and DSs can only be served at Cs. A spatially coherent network deals with the network in which the service schedules of facilities at various levels are compatible. Namely, patients served by a lower-level health facility can only be referred to the higher-level health facility that this facility is dependent on. In a spatially non-coherent network, restrictions on health seeking treatments do not exist.

The hierarchical healthcare network of the Golestan province of Iran is presently not well built and designed. It can be considered a multi-flow, nested, and spatially non-coherent network. The high volume of patients searching for OSs and ISs at Hs and MCs, specifically in Gorgan and Gonbad-e Kavus counties, is partly due to the unbalanced IS capacities compared to other counties with long-distance patient travel demand. Consequently, higher-level facilities are bustling and overworked, specifically MCs. It is reasonable to hope that the proper location of different health facilities would improve the access efficiency of a median hierarchical healthcare network and the performance of medical services by assigning more patients to health facilities with the minimum acceptable patient distance.

3.2 Median-based hierarchical location-allocation model for healthcare facilities

Healthcare facility location problems can be studied with three levels. For such facilities, hierarchical models of p-median problems can be used for formulating these problems. So, we formulate a median hierarchical location-allocation problem on the healthcare network (MHPHN) for locating a set of healthcare facilities with three levels where the total travel distance for patients is minimized. The sets, parameters, and decision variables are defined as follows:

Sets:	
I	The set of patient zones
J	The set of candidate locations for Cs
K	The set of candidate locations for Hs
L	The set of candidate locations for MCs
M	The set of existing locations for Cs
N	The set of existing locations for Hs
O	The set of existing locations for MCs
S	The set of healthcare service provider types (i.e., PH, DSs, OS, IS)

Input parameters:	
d_{ij}	The travel distance between patient zone $i \in I$ and a C in $j \in J \cup M$
d_{ik}	The travel distance between patient zone $i \in I$ and a H in $k \in K \cup N$
d_{jk}	The travel distance between a C in $j \in J \cup M$ and a H in $k \in K \cup N$
d_{jl}	The travel distance between a C in $j \in J \cup M$ and a MC in $l \in L \cup O$
d_{kl}	The travel distance between a H in $k \in K \cup N$ and a MC in $l \in L \cup O$
w_i	The population size at patient zone $i \in I$
C_j^s	The capacity of a C in $j \in J \cup M$ for healthcare service $s \in S$
C_k^s	The capacity of a H in $k \in K \cup N$ for healthcare service $s \in S$
C_l^s	The capacity of a MC in $l \in L \cup O$ for healthcare service $s \in S$
p	The maximum number of Cs to be established
q	The maximum number of Hs to be established
r	The maximum number of MCs to be established
θ_1	The proportion of patients in a C referred to a H for OS
θ_2	The proportion of patients in a C referred to a MC for Iss
θ_3	The proportion of patients in a H referred to a MC for Iss

Decision variables:	
x_j	1, if a C is built at candidate location $j \in J$; 0 otherwise
y_k	1, if a H is built at candidate location $k \in K$; 0 otherwise
z_l	1, if a MC is built at candidate location $l \in L$; 0 otherwise
u_{ij}^s	The flow of patients between demand point $i \in I$ and a C at $j \in J \cup M$ for healthcare service $s \in S$
u_{ik}^s	The flow between patient zone $i \in I$ and a H at $k \in K \cup N$ for healthcare service $s \in S$
v_{jk}^s	The flow of patients referred from a C at $j \in J \cup M$ to a H at $k \in K \cup N$ for healthcare service $s \in S$
v_{jl}^s	The flow of patients referred from a C at $j \in J \cup M$ to a MC at $l \in L \cup O$ for healthcare service $s \in S$
v_{kl}^s	The flow of patients referred from a H at $k \in K \cup N$ to a MC at $l \in L \cup O$ for healthcare service $s \in S$

MHPHN can be formulated as follows:

$$\min f = \sum_{i\in I}\sum_{j\in J\cup M}\sum_{s\in S} d_{ij}u_{ij}^s + \sum_{i\in I}\sum_{k\in K\cup N}\sum_{s\in S} d_{ik}u_{ik}^s + \sum_{j\in J\cup M}\sum_{k\in K\cup N}\sum_{s\in S} d_{jk}v_{jk}^s + \sum_{j\in J\cup M}\sum_{l\in L\cup O}\sum_{s\in S} d_{jl}v_{jl}^s + \sum_{k\in K\cup N}\sum_{l\in L\cup O}\sum_{s\in S} d_{kl}v_{kl}^s \tag{1}$$

s.t.

$$\sum_{j\in J\cup M} u_{ij}^s + \sum_{k\in K\cup N} u_{ik}^s = w_i, i\in I, s\in S \tag{2}$$

$$\sum_{k\in K\cup N} v_{jk}^s = \theta_1 \sum_{i\in I} u_{ij}^s, j\in J\cup M, s\in S \tag{3}$$

$$\sum_{l\in L\cup O} v_{jl}^s = \theta_2 \sum_{i\in I} u_{ij}^s, j\in J\cup M, s\in S \tag{4}$$

$$\sum_{l\in L\cup O} v_{kl}^s = \theta_3 \sum_{i\in I} u_{ik}^s, k\in K\cup N, s\in S \tag{5}$$

$$\sum_{i\in I} u_{ij}^s \le C_j^s x_j, j\in J\cup M, s\in S \tag{6}$$

$$\sum_{i\in I} u_{ik}^s + \sum_{j\in J\cup M} v_{jk}^s \le C_k^s y_k, k\in K\cup N, s\in S \tag{7}$$

$$\sum_{j\in J\cup M} v_{jl}^s + \sum_{k\in K\cup N} v_{kl}^s \le C_l^s z_l, l\in L\cup O, s\in S \tag{8}$$

$$\sum_{j\in J} x_j = p \tag{9}$$

$$\sum_{k\in K} y_k = q \tag{10}$$

$$\sum_{l\in L} z_l = r \tag{11}$$

$$x_j, y_k, z_l \in \{0,1\} j\in J, k\in K, l\in L \tag{12}$$

$$u_{ij}^s, u_{ik}^s, v_{jk}^s, v_{jl}^s, v_{kl}^s \ge 0 \cdots i\in I, j\in J\cup M, k\in K\cup N, l \in L\cup O, s\in S \tag{13}$$

The objective function minimizes the total travel distance. This objective value is modeled in Eq. (1), in which the first term shows the total distance from patients to the nearest Cs when new Cs are opened, and the second term states the same for the Hs opened, i.e., the total distance from patients to nearest Hs. The objective value also considers the total distance between Cs and Hs, the total distance between Cs and MCs, and the total distance between Hs and MCs for referred patients in terms of third, fourth, and fifth terms, respectively. Constraints (2) demonstrate that the entire population of patients must be assigned to Cs or Hs for primary healthcare, DS, or OS. Constraints (3) stipulate that θ_1 the proportion of patients that will be sent from an C to an H for OS. Constraints (4) stipulate that θ_2 the proportion of patients in a C referred to an MC for IS. Constraints (5) stipulate that θ_3 the proportion of patients in an H referred to an MC for IS. Constraints (6), (7) and (8) control the capacities of open and existing locations. Constraints (9), (10), and (11) specify the total number of Cs, Hs, and MCs to be built. Constraints (12) and (13) are domain constraints.

4 ICA

4.1 Continuous imperialist competitive algorithm

Atashpaz-Gargari and Lucas [37] first developed the continuous imperialist competitive algorithm (CICA). This method has been applied in many works in the OR field to solve.

NP-hard problems to obtain optimal and feasible solutions. For example, defensive location problem [38], flexible job-shop scheduling problem [39], traveling salesman problem [40] or multi-product distribution planning problem [41], the implementation of ICA is reported.

In the CICA, each answer has an array data structure called country. In an N_{var}-dimensional problem, each country is a vector with a length of N_{var}. Its objective function of it is defined through the variables $(P_1, P_2, \ldots, P_{N_{\text{var}}})$ in Eq. (14):

$$\text{Objective function}_i = f(\text{country}_i) = f(P_1, P_2, \ldots, P_{N_{\text{var}}}) \tag{14}$$

Determination of the best country is the aim of the CICA. In the minimization programming problem, the best country is one that has a smaller objective function. To begin this method, create some countries (N_{country}). Thus, the random matrix of countries is created as Eq. (15):

$$\text{COUNTRY} = \begin{bmatrix} \text{country}_1 \\ \text{country}_2 \\ . \\ . \\ . \\ \text{country}_{N_{\text{country}}} \end{bmatrix} \tag{15}$$

In this method, all countries are classified into several empires. In the first phase, some of the richest countries are selected as the initial imperialists, and the residual less potent is their colonies. The colonies were distributed among the imperialists based on the position and the potency of imperialists. The power is the inverse of their objective functions. The number of imperialists is indicated byN_{imp}, and the colonies of each imperialist are displayed by N_{col}. Each country is assigned to an empire based on the potency of imperialists. The normalized objective (C_n) of an imperialist is defined as Eq. (16):

$$C_n = f_{\text{cost}}^{\text{imp,n}} - \max_i (f_{\text{cost}}^{\text{imp,n}}) \tag{16}$$

Here $f_{\text{cost}}^{\text{imp,n}}$ indicates the objective value of the n th imperialist. Concerning the imperialists' potency or normalized objective, which is computed as Eq. (17), the initial colonies are distributed among empires, and for the n th empire, it is denoted as Eq. (18):

$$P_n = \left| \frac{C_n}{\sum_{i=1}^{N_{\text{imp}}} C_i} \right| \tag{17}$$

$$NC_n = \text{round}(P_n, N_{\text{col}}) \tag{18}$$

In the next phase, as stated in the absorption procedure as a mechanism to move countries to their better position with their minimum objective function, the imperialist countries assimilate the colonies toward themselves. The movement of colonies toward relevant imperialists in absorption strategy is illustrated in Fig. 1, in which d shows the distance between imperialist and colony, and x indicates a random value uniformly dispensed between 0 and $\lambda \times d$. Here λ is a parameter close to 2. V vector has a unity length, and its beginning point is the previous position of the colony toward the imperialist location.

$$\vec{X}_{\text{new}} = \vec{X}_{\text{old}} + U(0, \lambda \times d) \times \vec{V} \tag{19}$$

In Eq. (20), a random value of θ updates the movement's direction. This parameter is considered to improve the search operations by progressing the search area neighboring the imperialist.

$$\theta \approx U(-\gamma, +\gamma) \tag{20}$$

Here γ shows a parameter that selects a random value, and the searching area of colonies neighboring the imperialist will be changed. The movement of colonies toward relevant imperialist is modified, as indicated in Fig. 2.

The last phase in CICA is the imperialist competition, where all empires try to acquire other empires' colonies. Due to the gradual potency decrease in the powerless empires, their colonies were reduced and transferred to the stronger ones. This competition is done by selecting the weakest colony of the weakest empire and transferring it to the strongest empire, based on competition among all empires. To mimic this phase, the proprietorship probability must be derived by considering the empire's total potency. The empire's total potency is obtained by adding imperialist potency to an arbitrary percentage of the mean potency of its colonies as Eq. (21):

$$T.C_n = \text{Cost}(\text{imperialist}_n) + \zeta \times \text{mean}\{\text{Cost}(\text{coloniesof empire}_n)\} \tag{21}$$

$T.C_n$ is the total objective of an empire, ζ is a small positive value, and defines the duty of colonies in computing the potency of an empire. The total normalized objective of an empire is specified as Eq. (22):

$$N.T.C_n = \max_i (T.C_i) - T.C_n \tag{22}$$

The ownership probability is computed for each empire as Eq. (23):

$$P_{P_n} = \left| \frac{N.T.C_n}{\sum_{i=1}^{N_{\text{imp}}} N.T.C_i} \right| \tag{23}$$

Based on the ownership probability of each empire, the vector of ownership probability is indicated as Eq. (24):

$$P_{P_n} = \left[P_{P_1} P_{P_2} \ldots P_{P_{N_{\text{imp}}}} \right] \tag{24}$$

Also, the random vector R with the same size as the P vector is defined:

$$R = [r_1, r_2, \ldots, r_{N_{\text{imp}}}] \tag{25}$$

where each r_i follows a uniform distribution between 0 and 1. Lastly, the D vector will be formed, and for the empire with the highest D index value, the named colonies will be added to that empire, and it will be stronger. Figure 3 indicates the flowchart of the CICA on solving continuous optimization problems.

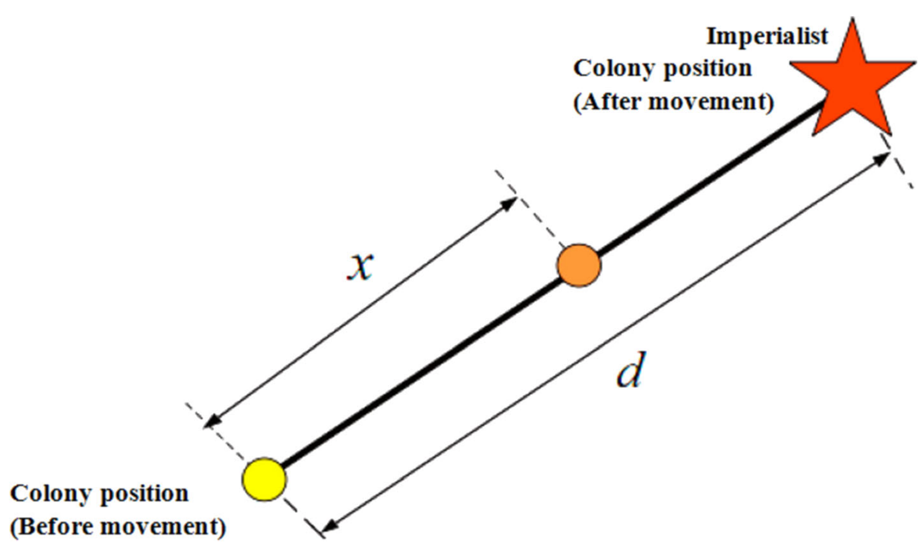

Fig. 1 Movement of colonies toward relevant imperialist

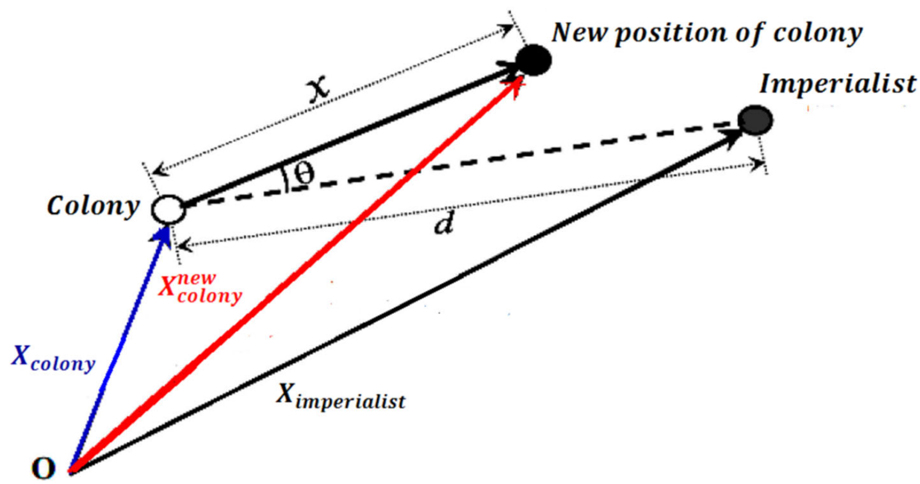

Fig. 2 Movement of colonies toward relevant imperialism based on θ angle

4.2 BICA

As explained in Sect. 3.1, the C, H, and MC location (CHML) vectors were three binary decision vectors in which the bit values $x_j = 1, y_k = 1, z_l = 1$ showed the installation of C, H and MCs, respectively, and the 0 values signified the non-installation of C, H, and MC. Thus, we had a mathematical programming problem with binary variables that we could execute a BICA. Therefore, in this subsection, the BICA was discussed in detail. Here, the decision vector length was defined as the number of candidate points in which health service providers were settled. In the BICA, the status of each country can be varied by 0 and 1. Thus, the assimilation operator (AO) and revolution operator (RO) would be varied versus the CICA.

In the first phase of the BICA, the status of each country was randomly created by 0 and 1 s. On the AO of the BICA, each country moved toward its imperialist with a probability concerning v as Eqs. (26) and (27). So, a transfer function (TF) was considered for mapping v into a fit and good probability value. Namely, the TF specified the probability of swapping 0 to 1 and vice versa. In reality, the TF confined the locations to move in solution space for this problem with three binary decision variables. Suppose the

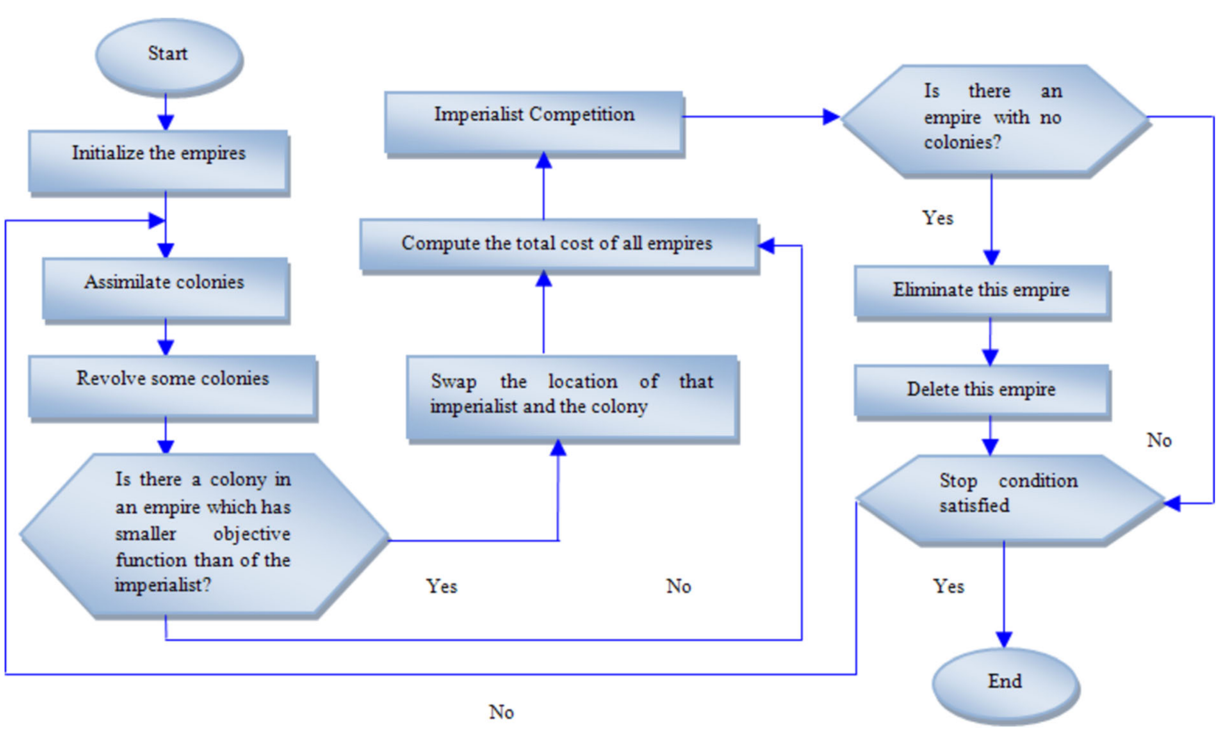

Fig. 3 Flowchart of CICA

colony and its imperialist were at a great distance. In that case, the TF should create a more significant probability of swapping the colony's status; a lesser probability value is needed if this distance is less. The range of the TFs was an interval that includes 0, 1, and all real numbers in between, and its value would be decreased from 1 to 0 by decreasing the distance between the colonies from their imperialists. In this subsection, different TFs were introduced for the BICA. These TFs are indicated in Table 2. The TFs 1–4 were the well-known S-Shapes, and the functions 5–9 were the well-known V-Shapes.

If the status of country i in binary N_{var}-dimensional solution area in repetition t was described as $X_i(t) = \left[x_i^1, x_i^2, \ldots, x_i^{N_{\text{var}}}\right]$, the next status of country i in dimension k would be specified by Eqs. (26) or (27). If the functions TF1 to TF4 were applied, the $x_i^k(t+1)$ would be calculated by Eq. (26), if the applied TFs are TF5 to TF9, then the $x_i^k(t+1)$ would be specified as Eq. (27). In reality, in the BICA, the AO was varied as it was defined.

$$x_i^k(t+1) = \begin{cases} 0 \; if \; rand < S(v_i^k(t+1)) \\ 1 \; if \; rand \geq S(v_i^k(t+1)) \end{cases} \tag{26}$$

$$x_i^k(t+1) = \begin{cases} Not(x_i^k(t)) \; if \; rand < S(v_i^k(t+1)) \\ x_i^k(t) \; if \; rand \geq S(v_i^k(t+1)) \end{cases} \tag{27}$$

The procedure of the RO also varied for the BICA. This operator corresponds to the mutation operator in genetic methods. Thus a bit was randomly chosen with a definite probability; if the value of the chosen bit was 0, it would swap to 1 and vice versa.

4.3 BICA for the MHPHN

BICA began with a population of countries. A country X in BICA was described as a binary vector in the solution area with N_{var} variables as Eq. (28).

Table 2 TFs (Mirhosseini and Nezamabadi-pour [42])

Number	Name	TF
1	TF1	$S(v) = \frac{1}{1+e^{-2v}}$
2	TF2	$S(v) = \frac{1}{1+e^{-v}}$
3	TF3	$S(v) = \frac{1}{1+e^{-\frac{v}{2}}}$
4	TF4	$S(v) = \frac{1}{1+e^{-\frac{v}{3}}}$
5	TF5	$S(v) = \left\lvert \frac{2}{\sqrt{\pi}} \int_0^{\frac{\sqrt{\pi}}{2}v} e^{-t^2} dt \right\rvert$
6	TF6	$S(v) = \tanh(v)$
7	TF7	$S(v) = \left\lvert \frac{v}{\sqrt{1+v^2}} \right\rvert$
8	TF8	$S(v) = \left\lvert \frac{2}{\pi} \arctan(\frac{\pi}{2} v) \right\rvert$
9	TF9	$S(v) = 2 \times \left\lvert \frac{1}{1+e^{-v}} - 0.5 \right\rvert$

In an MHPHN, each binary variable x_i, in a country X displayed placement (1) or non-placement (0) of locations.

$$X = [x_1, x_2, \ldots, x_{N_{\text{var}}}], x_i \in \{0,1\} \tag{28}$$

Then, a population of N_{pop} countries was first created with N_{imp} imperialists. The imperialists were chosen regarding their objective function $f(X_i)$ in Eq. (29),

$$f(X_i) = f(x_{i1}, x_{i2}, \ldots, x_{iN_{\text{var}}}) \tag{29}$$

N_{imp} countries with the best objective function were chosen as the imperialists. These imperialists got the residue $(N_{\text{pop}} - N_{\text{imp}})$ countries as their colonies to generate empires. The $N.X_{\text{imp}_n}$ colonies of n th imperialist corresponded to its objective function in Eq. (30). So, a better imperialist captured more colonies and generated a stronger empire. This allocation of colonies can be performed with the roulette wheel selection operator.

$$N.X_{\text{imp}_n} = \text{round}\left\{ \left\lvert \frac{f(X_{\text{imp}_n})}{\sum_{i=1}^{N_{\text{imp}}} X_{\text{imp}_i}} \right\rvert .(N_{\text{pop}} - N_{\text{imp}}) \right\} \tag{30}$$

Empires attempted to increase their colonies with AO and RO. In the AO, imperialists exerted better components on their colonies to improve their total potency. The AO was executed by proceeding the colonies toward their respective imperialist. In BICA, colonies move was performed concerning the Hamming distance D. A colony would travel d bits toward the imperialist as given in Eq. (31).

$$d \approx U(0, D) \tag{31}$$

Here, U was the discrete uniform distribution function.

A colony's random commotion can prevent it from lying in a local solution. An RO applied for exploitation obtains this commotion. In the RO, an ideal replacement in a colony was produced. If this sudden replacement improved a colony, the new colony was saved; otherwise, it was eliminated. In BICA, it was executed with a mutation operator.

Change in colonies via AO and RO can obtain better colonies. If these colonies were better than their imperialist, then the best colony and its imperialist places were replaced. This operation kept the situation of the best local colony (imperialist); therefore, the AO would apply this new imperialist.

As illustrated by CICA, empires attempted to increase their potency or keep it. The BICA began a competition between empires to improve their potency and gained more and more colonies. Thus, better empires tried to get the weakest colony (based on their objective function) from the worst empire. The favoritism of empires was performed concerning their potency ($P.E$). The potency of an empire

$(P.E_n)$ was computed as the total of its imperialist and a percentage of its colonies' mean potency as given in Eq. (32).

$$P.E_n = f\left(X_{\text{imp}_n}\right) + \zeta.\text{mean}\{f(\text{coloniesof empire}E_n)\} \tag{32}$$

In this imperialistic competition procedure, weaker empires weaken and break down into stronger ones. Finally, only one empire survived, which was a stopping condition to end the BICA.

Using the BICA, a method for the optimal location of Cs, Hs, and MCs is defined in the following steps:

Step 1:	Input data $I,J,K,L,M,N,O,S,d_{ij},d_{ij},d_{ij},d_{ik},d_{jk},d_{jl},d_{ij},d_{ij},d_{kl},w_i,C_j^s,C_k^s,C_l^s$, p,q,r, θ_1, θ_2,θ_3 is attained;
Step 2:	The initial population of countries (CHML vectors), i.e., the vectors of the solution in BICA, is randomly generated. It should be pointed out that as the CHML vectors are specified, for each $i \in I, j \in J \cup M, k \in K \cup N, l \in L \cup O, s \in S$, the paths for routing the flow of patients $u_{ij}^s, u_{ik}^s, v_{jk}^s, v_{jl}^s, v_{kl}^s$ are attained by solving the shortest path problem;
Step 3:	Analysis of the CHML vectors from the standpoint of restrictions is performed. If not met, so it should change the CHML vectors until constraints' satisfaction is acquired;
Step 4:	Total decision indicators with the MHPHN, such as the total distance from patients to the nearest Cs, the total distance between patients and nearest Hs, the total distance between Cs and Hs, the total distance between Cs and MCs, and the total distance between Hs and MCs for referred patients are calculated;
Step 5:	Evaluation of the CHML vectors' efficiency with the concern of objective value (1) using determined indicators. Thus, for each country, it is calculated;
Step 6:	All countries are categorized into various empires. Here, some of the more potent countries, following computed objective functions in the previous step, are selected as the initial imperialists, and the residual less potency are colonies of them and are scattered among imperialists concerning their potency;
Step 7:	The movement of colonies toward relevant imperialist is accomplished based on the absorption procedure;
Step 8:	Executing the imperialistic competition process. So, first, the ownership probability should be computed with Eq. (23);
Step 9:	The vector of ownership probability concerning the ownership probability value of each empire is obtained using Eq. (24);
Step 10:	The D vector is formed by Eq. (25), and the empire with the most D index value acquires more colonies, and that empire will be more potent;
Step 11:	Improving colonies with the AO. Equation (27) with TF TF9 is applied to update the colony position and each CHML vector to find a new situation with the binary AO
Step 12:	Steps 3–11 will be iterated until convergence is reached, in which there is one empire without colonies, the weakest empire is removed, and the best solution is obtained. Thus, the optimal location of Cs, Hs, and MCs is achieved

The BICA is also developed for the proposed MHPHN. Two improvement strategies are introduced in the BICA structure to enhance the search mechanism as follows:

I. Initialization mechanism: The heuristic methods concerning the effectiveness of the health services can be used to create better initial solutions with a better exploration of the MHPHN. To do this, an AO is also executed between the imperialists in BICA. As reported earlier, for colonies, the imperialists in a country move toward the imperialists of other countries to increase the power of that country. So, the imperialists can affect the other imperialists by their potency and distance between the two imperialists. The imperialist power in the MHPHN depends on the reverse function (RF), defined by $\mu_m = \frac{1}{RF_m}$. The power distance of two imperialists can be computed by the difference in power levels of imperialists, i.e., $\sigma_{nm} = |N.T.C_n - N.T.C_m|, m \neq n$. Thus, the influence of an imperialist in increasing the power of other imperialists is calculated by:

$$\omega_{nm} = \frac{\mu_m \sigma_{nm}}{\sum_{m=1,m\neq n}^{N_{\text{imp}}} \mu_m \sigma_{nm}} \tag{33}$$

So, possession probability is changed as follows:

$$P_{P_n} = \sigma_1 \left| \frac{N.T.C_n}{\sum_{i=1}^{N_{\text{imp}}} N.T.C_i} \right| + \sigma_2 \sum_{m=1,m\neq n}^{N_{\text{imp}}} \omega_{nm} \tag{34}$$

where σ_1 and σ_2 are two weights that equilibrate the impact of potency and distance between the colony and imperialist and the distance between two imperialists in the competition. Equation (34) allows an empire to acquire the weakest imperialist colonies more likely. So, it encouraged the strong empire to have more colonies, increasing the convergence. In this mechanism, the exploitation of the BICA is improved.

II. Local mechanism: A local improvement mechanism can enhance the solution quality. In an MHPHN, Cs, Hs, and MCs are changed repeatedly with the Cs, Hs, and MCs not in the solution until this exchange procedure gives a reasonable solution faster. Furthermore, one or more Cs, Hs, and MCs in the solution are chosen randomly, and non-placement locations are chosen for placement following a greedy method until the restrictions are not violated. For the MHPHN to locate Cs, Hs, and MCs, this algorithm selects the most "travel distance-effective" C (H and MC) until all p Cs (q Hs and r MCs) are located.

At first, an C (either H or MC) is located to minimize the total travel distance for all patients. Next, Cs (Hs and MCs)

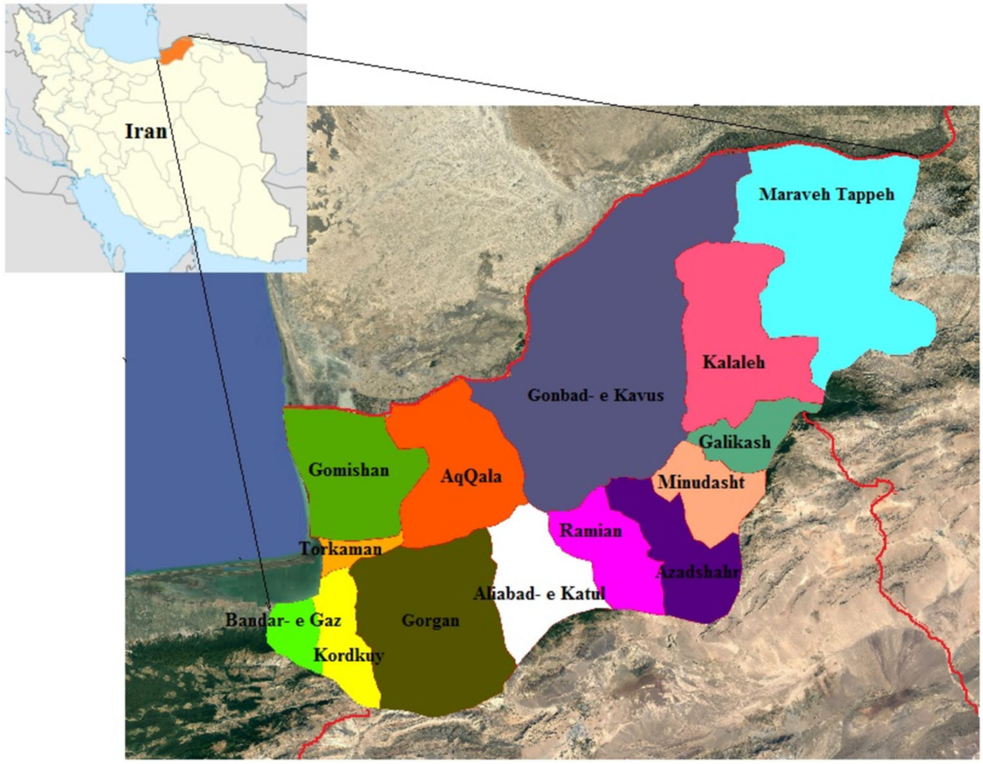

Fig. 4 Geographic location and the current counties of Golestan province in Iran

Table 3 A listing of counties and cities in Golestan Province

Number	County name	City name
1	Gorgan	Gorgan, Sarkhon Kalateh, Jelin-e Olya
2	Gonbad-e Kavus	Gonbad-e Kavus, Incheh Borun
3	Bandar Torkaman	Bandar Torkaman
4	Aliabad-e Katul	Aliabad-e Katul, Fazelabad, Sangdevin, Mazraeh
5	Azadshahr	Azadshahr, Neginshahr, Now Deh Khanduz
6	Kordkuy	Kordkuy
7	Kalaleh	Kalaleh, Faraghi
8	AqQala	AqQala, Anbar Olum
9	Minudasht	Minudasht
10	Galikash	Galikash
11	Bandar-e Gaz	Bandar-e Gaz, Now Kandeh
12	Gomishan	Gomishan, Siminshahr
13	Ramian	Ramian, Khan Bebin, Daland, Tatar-e Olya
14	Maraveh Tappeh	Maraveh Tappeh

are added one by one until p (q and r) are achieved. This approach chooses the location that obtains the minimum travel distance. The primary problem with this mechanism is that once an C (H and MC) is chosen, it keeps on all the next solutions. Subsequently, the final solution obtained may be worse than the optimal solution. This mechanism is called Greedy-Add since the locations are added one by one to obtain the needed number of Cs (Hs and MCs). The reverse mechanism is called Greedy-Drop, which begins with Cs (Hs and MCs) located at all possible C (H and MC) places and then deleting (drops) the C (H and MC) that has minimal influence on the objective value. This mechanism deletes the locations one by one so long as the needed p Cs (q Hs and r MCs) stay.

Table 4 Location of current health facilities in Golestan province of Iran

County name	City name	Facility name	Facility type	Node number
Gorgan	Gorgan	Sayyad Shirazi	MC	1
	Gorgan	Dazyani	H	2
	Gorgan	5th Azar	MC	3
	Gorgan	Army 560	MC	4
	Gorgan	Masoud	MC	5
	Gorgan	Taleghani	MC	6
	Gorgan	Dr Mousavi	MC	7
	Gorgan	Falsafi	MC	8
	Gorgan	Hakim Jorjani	MC	9
	Gorgan	Shafa Heart	MC	10
Gonbad-e Kavus	Gonbad-e Kavus	Shohada	H	11
	Gonbad-e Kavus	Beski	MC	12
	Gonbad-e Kavus	Borzouyeh	MC	13
	Gonbad-e Kavus	Khatamolanbia	MC	14
	Gonbad-e Kavus	Shahid Motahari	MC	15
	Gonbad-e Kavus	Payambar Azam	MC	16
	Gonbad-e Kavus	Taleghani	H	17
Aliabad	Aliabad	Baghiatolah Azam	H	18
	Aliabad	Ghaem	C	19
Azadshahr	Azadshahr	Hazrat Masoumeh	H	20
Kordkuy	Kordkuy	Amiralmomenin	MC	21
Bandar-e Gaz	Bandar-e Gaz	Shohada	MC	22
Torkaman	Torkaman	Imam Khomeini	H	23
AqQala	AqQala	Al Jalil	H	24
Ramian	Khanbebin	Imam Reza	H	25
Minudasht	Minudasht	Fatimatuzzahra	H	26
Kalaleh	Kalaleh	Rasul Akram	H	27
Gomishan	Siminshahr	Siminshahr	C	28
	Gomishan	Health center	C	29
Galikash	Galikash	Shohada 12 dey	C	30
Maraveh Tappeh	Maraveh Tappeh	Loghman Hakim	C	31

5 Case study—data and results

The resolution of an actual case study in this part illustrates the model's applicability. Iran's Golestan province is used as the model's application. This section describes the data used before providing specific information on the Golestan province's healthcare system. The outcomes of a few policy-relevant illustration scenarios are then presented and analyzed.

5.1 Golestan province

Iran has an administrative division with thirty-one provinces, each governed from a local center, usually the largest local city, which is called the capital of that province. Each province is further subdivided into counties, and each county is subdivided into districts. There are usually a few cities and rural districts in each district. This work focuses on the Golestan province, which contains a population of about 1.9 million people and includes twenty-nine cities and fourteen counties, as depicted in Fig. 4. Table 3 lists cities and counties. The Golestan Province (53°57′- 56°23′ E, 36°30′- 38°08′ N) is located in the northeast of Iran, bordering the Caspian Sea and Turkmenistan country. This province has an area of 20,437.74 km^2. The province has a dry and semi-arid climate in the northern and northeastern parts, a temperate climate in the central parts, and a mountainous and cold climate in the southern parts.

Golestan province is the rainbow of tribes, religions, and subcultures, known as the cultural capital of the tribes. According to the 1995 census, the population of Golestan is 1,868,819 people, including Torkaman, Mazanderani, Baluch, Turkic (Azeris and Qizilbash), Sistani, Kurdish,

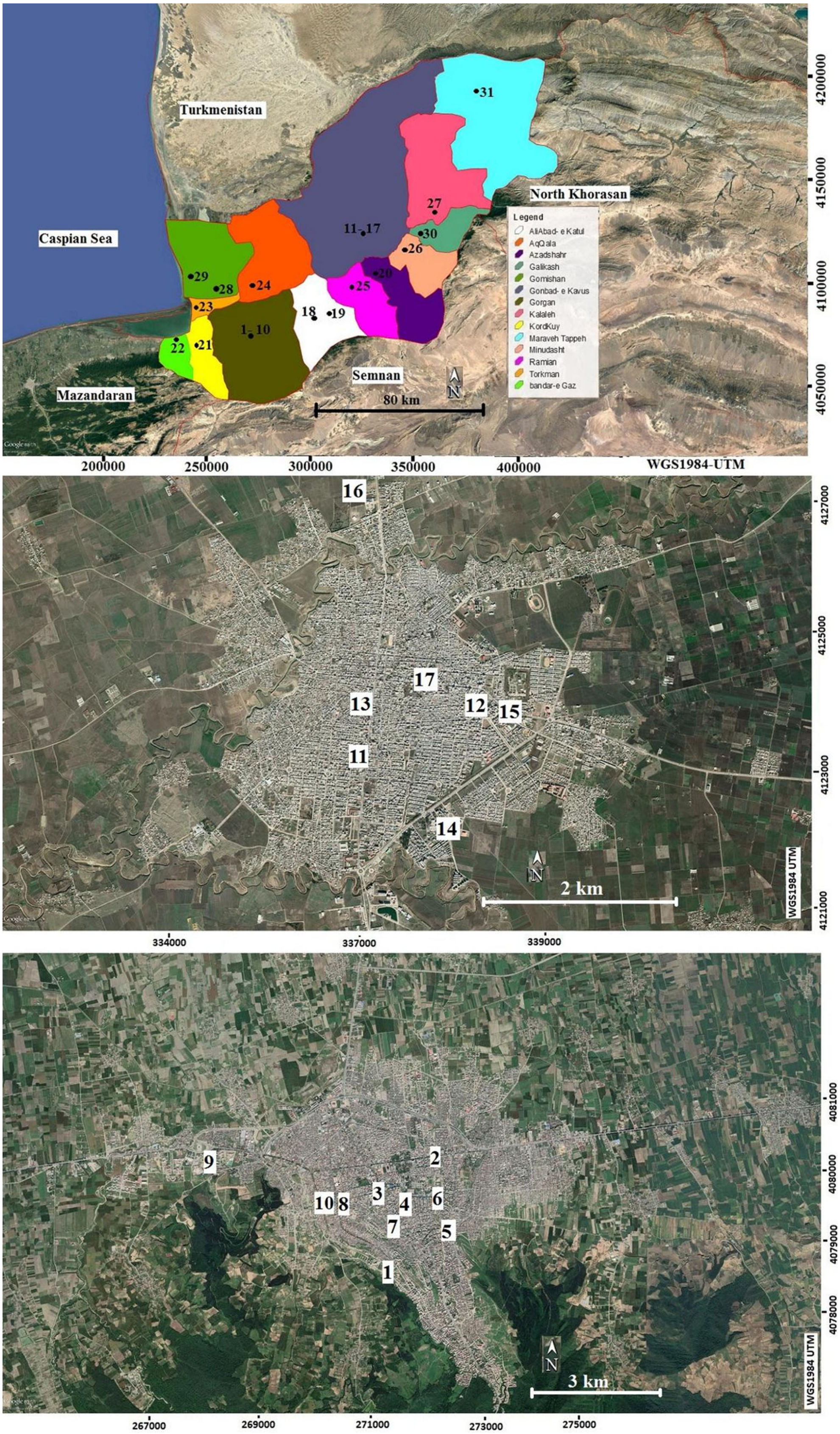

Fig. 5 Golestan province with its health facilities

Table 5 Population of the counties in Golestan Province based on the 2016 census

Number	City name	County name	Population	New C	New H	New MC
1	Gorgan	Gorgan	350,676	C1	H1	M1
2	Sarkhon Kalateh	Gorgan	7589	C2	H2	M2
3	Jelin-e Olya	Gorgan	7417	C3	H3	M3
4	Gonbad-e Kavus	Gonbad-e Kavus	151,910	C4	H4	M4
5	Incheh Borun	Gonbad-e Kavus	2494	C5	H5	M5
6	Bandar Torkaman	Bandar Torkaman	53,970	C6	H6	M6
7	Aliabad-e Katul	Aliabad-e Katul	52,838	C7	H7	M7
8	Sangdevin	Aliabad-e Katul	4203	C8	H8	M8
9	Fazelabad	Aliabad-e Katul	19,461	C9	H9	M9
10	Mazraeh	Aliabad-e Katul	4009	C10	H10	M10
11	Azadshahr	Azadshahr	43,760	C11	H11	M11
12	Neginshahr	Azadshahr	8138	C12	H12	M12
13	Now Deh Khanduz	Azadshahr	2989	C13	H13	M13
14	Kordkuy	Kordkuy	39,881	C14	H14	M14
15	Kalaleh	Kalaleh	36,176	C15	H15	M15
16	Faraghi	Kalaleh	5777	C16	H16	M16
17	AqQala	AqQala	35,116	C17	H17	M17
18	Anbar Olum	AqQala	7003	C18	H18	M18
19	Minudasht	Minudasht	30,085	C19	H19	M19
20	Galikash	Galikash	23,394	C20	H20	M20
21	Bandar-e Gaz	Bandar-e Gaz	20,742	C21	H21	M21
22	Now Kandeh	Bandar-e Gaz	6650	C22	H22	M22
23	Gomishan	Gomishan	19,191	C23	H23	M23
24	Siminshahr	Gomishan	17,205	C24	H24	M24
25	Ramian	Ramian	12,426	C25	H25	M25
26	Khan Bebin	Ramian	10,878	C26	H26	M26
27	Daland	Ramian	8184	C27	H27	M27
28	Tatar-e Olya	Ramian	4782	C28	H28	M28
29	Maraveh Tappeh	Maraveh Tappeh	8671	C29	H29	M29

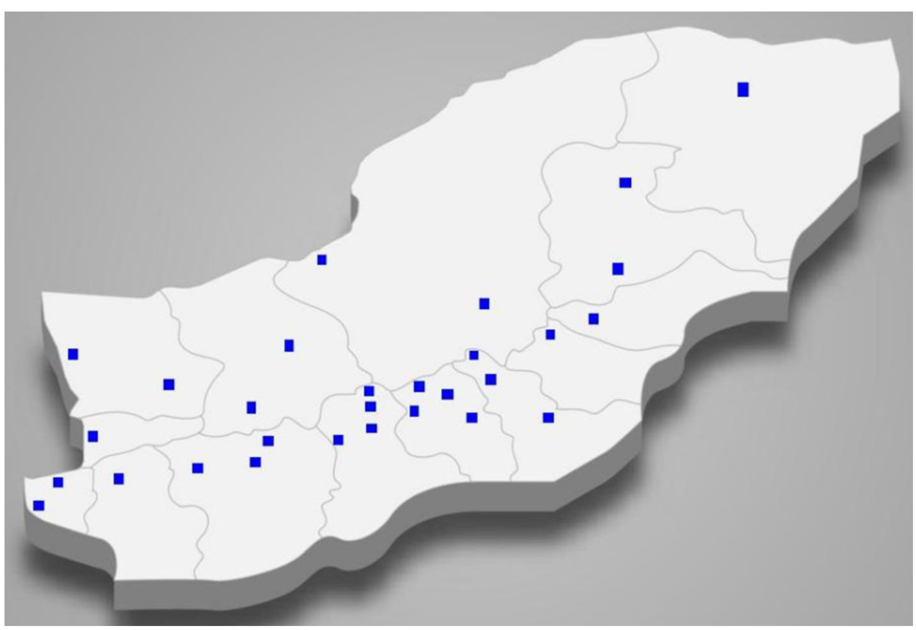

Fig. 6 Candidate locations for health facilities in Golestan province

and Kazakh. The Sistani and Baluch people live mostly in the center and south of the province, and the Mazanderani live in the west and south of the province and speak Tabari and Farsi languages. Qizilbash people live in Ramian, Azadshahr, Minudasht, Kalaleh, and Galikash, Azeris live in Gonbad-e Kavus county, and a small number live in Minudasht, and Kazakhs mostly live in Gorgan. Also, Kurds have a significant population in counties such as Gonbad-e Kavus. Turkmen live in the eastern, central, and northern parts of the province and the center of the province. They speak the Turkmen language.

The capabilities of the Golestan medical industry, such as a noticeable number of MCs in Gorgan and Gonbad-e Kavus counties, distinguished medical specialists, high-quality ISs, good weather, tourist attractions, and appropriate hotels, numerous patients from all over the country, the neighboring countries of the Caspian sea travel to Golestan province to receive ISs.

Table 4 describes the healthcare network with 5 Cs, 9 Hs, and 16 MCs. Figure 5 also displays the configuration of the current health network, composed of 30 health facilities, 10 in Gorgan county, 7 in Gonbad-e Kavus county, and 14 remaining health facilities less spread across the Golestan province.

The province of Golestan consists of a variety of counties, cities, and rural areas. County and urban areas benefit from health services' accessibility and closer geographical proximity. In contrast, rural areas without access to healthcare have suffered population declines in recent years. The AqQala, Kalaleh, and Maraveh Tappeh counties contain the most rural and isolated areas.

5.2 Data in use

To demonstrate the usefulness of the novel mathematical model, we execute it in a case study based on the Golestan province of Iran country. In this case study, each city center is considered a patient node with various healthcare service demands. Table 5 provides the population of the counties in Golestan Province.

We measure the road *distance* between the cities and the Cs, Hs, or MCs *on Google Maps*. To meet a suitable healthcare service provider, the minimum distance satisfaction among patients is considered based on the appropriate distance in various possible routes from city locations and the health facilities.

The health facilities' *capacities* should vary by the C, H, and MC's locations, the service team, including doctors, nurses, and specialists, and the different services the health facility can provide. The α, β, γ are obtained based on some historical data and the experts' opinions.

The impact of Cs, Hs, and MCs opened in each potential location on the performance of the healthcare network through three different levels of resources (i.e., number and type of health facilities) are analyzed. In addition, 29 possible candidate locations for Cs, Hs, and MCs were considered located in 29 cities of Golestan province. The structure is shown in Fig. 6. In the 29 cities, 29 points are considered candidates for the health facility locations.

Table 6 Location of new Cs, Hs and MCs for the different scenarios with novel BICA

ID	p	q	r	θ_1 (%)	θ_2 (%)	θ_3 (%)	Objective	Time	New Cs	New Hs	New MCs
1	4	4	4	5	5	1	**60,190.3**	**77.3**	**C6,C14,C15,C21**	**H20,H22,H23,H25**	**M7,M11,M17,M29**
2	4	4	8	5	5	1	**56,001.8**	**92.5**	**C6,C8,C14,C19**	**H8,H18,H22,H24**	**M7,M11,M15,M17, M20,M23,M25,M29**
3	4	8	4	5	5	1	**57,105.2**	**88.6**	**C6,C12,C15,C17**	**H5,H8,H14,H18, H20,H22,H24,H25**	**M7,M11,M23,M29**
4	4	8	8	5	5	1	**52,185.4**	**106.8**	**C6,C14,C21,C27**	**H5,H8,H14,H18, H20,H22,H24,H25**	**M7,M11,M15,M17, M19,M23,M26,M29**
5	8	4	4	5	5	1	**58,489.7**	**84.8**	**C6,C8,C13,C14, C15,C19,C21,C26**	**H20,H22,H23,H25**	**M7,M11,M17,M29**
6	8	4	8	5	5	1	**53,045.1**	**114.4**	**C2,C5,C6,C8, C13,C14,C19,C26**	**H9,H18,H22,H24**	**M7,M11,M15,M17, M20,M23,M25,M29**
7	8	8	4	5	5	1	**53,970.6**	**102.7**	**C3,C6,C8,C12, C15,C17,C19,C27**	**H5,H9,H14,H18, H20,H22,H24,H25**	**M7,M11,M23,M29**
8	8	8	8	5	5	1	**50,092.2**	**128.2**	**C2,C6,C8,C13, C14,C16,C21,C27**	**H5,H9,H12,H18, H20,H22,H24,H25**	**M7,M11,M15,M17, M19,M23,M26,M29**

The best locations for health facilities

Table 7 Input parameters of BICA, BGA and BPSO

Algorithm	Parameter	Value
BGA	Number of population	100
	Maximum iteration	200
	Probability for crossover	0.7
	Probability for mutation	0.3
BPSO	Number of population	100
	Maximum iteration	200
	Acceleration coefficient associated with particle's own best position	2
	Acceleration coefficient associated with best position of any particle in whole swarm	2
BICA	Number of population	100
	Maximum iteration	200
	Revolution rate	0.2
	Number of imperialists	10
	Assimilation coefficient	2
	Assimilation angle	0.5
	Empire coefficient	0.05

These points contain the most population centers that also supply a range of health services that attract patients and smaller centers that already have an C, H, or MC.

5.3 Results for the designed scenarios

Three scenarios (scenarios I, II, and III) associated with various model inputs and metaheuristic approaches were chosen to demonstrate the usefulness of the proposed mathematical model. These scenarios aim to determine a unique solution to the optimal location, the assignment of the patient's needs to them, and the structure of the healthcare supply chain to help the future planning of a regional network of hierarchical health facilities.

A case study of the Golestan healthcare network is solved to show the model's suitability. The first scenario examines how altering the number of existing locations can increase patients' access to IS, OS, PH, DSs, and OS. For the second scenario, a sensitivity analysis is executed, indicating how robust the proposed BICA results are against other metaheuristic algorithms and the extent to which there is a trade-off between better access to Cs, Hs, and MCs and objective functions. The third scenario is based on directives from the Golestan province that show the necessity of constructing new medical facilities, including Cs, Hs, and centers for treatment, in response to changes in the percentage of referred demands. Tables 6, 8 present the obtained results based on various experiments. The model was implemented in MATLAB (R2018b) on a 64-bit computer, Intel Core i7, 3.3 GHz processor, and 4GB of RAM.

5.3.1 Scenario I

In scenario I, the changes to the current healthcare network to increase the number of new locations are considered. Constraints to locating new Cs, Hs, and MCs are three critical parameters of the proposed model that can improve the efficiency of the healthcare network under two various levels. Table 6 shows the change procedure in the total travel distance concerning the service and geographical accessibility for two levels of p, q and r.

The results for the MHPHN are represented in Table 6, where concerning scenario I, we can see in Table 6 the location of the new Cs, Hs, MCs, and the Cs' catchment areas (denoted by C1,…, C29), the Hs' catchment areas (denoted by H1,…, H29) and MCs' catchment areas (denoted by M1,…, M29). Table 6 is considered for comparing the new model results with the status of the current healthcare network, and it determines new information about total demand-weighted travel distance. So, if the designer wants to improve the accessibility of health services through the minimization of the total travel distance and simultaneously guarantee that.

1. The C meets the needs for PH and DSs,
2. The H supplies the services for OSs, PH, and DSs
3. The MC serves OSs and ISs

She/he should consider building several new locations in the populated city areas with a high density far from existing health facilities.

Table 6 indicates the impact of increasing the number of new Cs, Hs, and MCs in the total demand-weighted travel

Table 8 Numerical results from the sensitivity analyses with the metaheuristic methods

ID	p	q	r	θ_1 (%)	θ_2 (%)	θ_3 (%)	New BICA		BICA		BGA		BPSO	
							Objective	Time	Gap	Time	Gap	Time	Gap	Time
1	4	4	4	5	5	1	60,190.3	77.3	2.74	97.2	5.06	112.5	9.56	140.5
2	4	4	8	5	5	1	56,001.8	92.5	2.64	115.7	4.82	136.7	9.47	167.3
3	4	8	4	5	5	1	57,105.2	88.6	2.83	108.5	5.37	128.2	10.13	156.6
4	4	8	8	5	5	1	52,185.4	106.8	2.35	134.7	4.81	154.3	9.25	194.4
5	8	4	4	5	5	1	58,489.7	84.8	2.56	104.5	4.45	123.5	8.83	150.8
6	8	4	8	5	5	1	53,045.1	114.4	2.83	145.5	5.52	165.7	10.31	209.5
7	8	8	4	5	5	1	53,970.6	102.7	3.24	128.3	6.26	147.9	12.01	184.8
8	8	8	8	5	5	1	50,092.2	128.2	3.15	157.7	6.11	180.9	11.43	227.1
9	4	4	4	5	5	2	61,697.5	87.1	2.87	107.6	5.59	123.8	10.74	155.3
10	4	4	8	5	5	2	57,406.9	101.8	3.16	128.3	6.13	147.1	11.27	185.1
11	4	8	4	5	5	2	58,537.9	98.3	2.65	120.4	5.17	138.7	10.27	173.4
12	4	8	8	5	5	2	53,485.8	116.5	3.42	148.2	6.41	173.4	12.39	213.4
13	8	4	4	5	5	2	59,952.1	93.1	2.88	115.2	5.24	135.6	9.86	165.9
14	8	4	8	5	5	2	54,370.2	129.4	2.63	160.1	4.58	183.6	8.98	230.3
15	8	8	4	5	5	2	55,323.6	113.7	3.41	141.2	6.57	162.8	12.61	203.4
16	8	8	8	5	5	2	51,346.5	137.2	3.35	173.5	6.12	204.2	11.23	249.8
17	4	4	4	10	5	1	61,092.1	115.5	2.78	146.8	5.52	174.3	10.42	211.1
18	4	4	8	10	5	1	56,846.8	141.2	2.84	175.3	5.63	201.3	10.63	252.5
19	4	8	4	10	5	1	57,961.2	133.4	3.15	164.2	5.82	192.5	11.28	236.2
20	4	8	8	10	5	1	52,965.1	162.7	3.23	202.1	6.53	232.4	12.33	291.6
21	8	4	4	10	5	1	59,366.3	123.7	2.95	157.2	5.45	184.2	10.57	226.2
22	8	4	8	10	5	1	53,840.8	171.6	2.81	218.5	5.28	251.1	10.43	314.8
23	8	8	4	10	5	1	54,782.2	152.1	2.84	192.6	5.35	225.3	10.28	277.9
24	8	8	8	10	5	1	50,845.6	187.3	2.38	236.5	4.68	270.4	8.91	340.7
25	4	4	4	10	5	2	62,622.4	128.1	2.69	161.4	5.06	185.3	9.73	232.5
26	4	4	8	10	5	2	58,265.9	156.2	2.77	192.8	4.93	223.6	9.47	277.6
27	4	8	4	10	5	2	59,412.6	146.5	2.65	180.6	5.37	210.5	10.21	260.1
28	4	8	8	10	5	2	54,291.4	175.8	3.22	222.3	6.61	254.9	12.39	320.6
29	8	4	4	10	5	2	60,852.3	136.2	3.56	172.3	6.43	201.4	12.08	248.8
30	8	4	8	10	5	2	55,187.8	190.6	3.13	240.5	5.97	275.4	11.56	345.7
31	8	8	4	10	5	2	56,151.2	165.4	3.41	211.9	6.39	241.7	12.36	305.1
32	8	8	8	10	5	2	52,115.1	205.2	3.14	260.2	5.89	302.9	11.04	370.8
33	4	4	4	5	10	1	61,690.7	107.6	2.59	137.1	4.97	156.4	9.64	199.3
34	4	4	8	5	10	1	57,401.2	133.9	2.78	163.6	5.34	188.8	9.76	236.6
35	4	8	4	5	10	1	58,532.9	125.6	2.64	153.3	5.44	175.2	10.18	223.7
36	4	8	8	5	10	1	53,489.8	150.2	2.78	188.6	5.62	214.3	10.02	274.6
37	8	4	4	5	10	1	59,952.5	116.3	2.54	146.5	5.16	171.1	9.82	215.1
38	8	4	8	5	10	1	54,370.2	164.6	2.61	203.7	5.31	235.2	9.72	292.3
39	8	8	4	5	10	1	55,321.6	140.7	2.65	179.5	4.92	209.4	9.51	259.8
40	8	8	8	5	10	1	51,344.5	174.8	2.48	220.8	4.87	257.6	9.25	315.2
41	4	4	4	5	10	2	63,232.4	120.5	2.59	150.7	4.59	173.4	9.39	216.4
42	4	4	8	5	10	2	58,843.3	141.9	2.87	179.9	5.32	205.6	9.83	255.1
43	4	8	4	5	10	2	59,996.3	137.4	2.73	168.6	5.42	192.1	10.22	248.8
44	4	8	8	5	10	2	54,822.1	165.2	2.99	207.5	5.36	241.7	9.94	299.2
45	8	4	4	5	10	2	61,447.4	129.1	2.95	161.3	5.25	185.2	10.37	235.2
46	8	4	8	5	10	2	55,730.6	178.5	2.98	224.7	5.32	258.9	10.52	325.6
47	8	8	4	5	10	2	56,705.1	155.1	2.74	197.6	5.16	229.3	9.82	282.8

Table 8 (continued)

ID	p	q	r	θ_1 (%)	θ_2 (%)	θ_3 (%)	New BICA		BICA		BGA		BPSO	
							Objective	Time	Gap	Time	Gap	Time	Gap	Time
48	8	8	8	5	10	2	**52,631.3**	**196.4**	**2.61**	**242.9**	**5.39**	**283.8**	**9.97**	**344.6**
49	4	4	4	10	10	1	**62,593.2**	**149.7**	**3.15**	**185.3**	**5.92**	**214.7**	**11.28**	**265.7**
50	4	4	8	10	10	1	**58,240.9**	**175.6**	**3.41**	**222.3**	**6.29**	**255.5**	**12.36**	**315.7**
51	4	8	4	10	10	1	**59,392.8**	**165.4**	**3.25**	**208.5**	**6.31**	**244.3**	**11.63**	**294.5**
52	4	8	8	10	10	1	**54,272.7**	**201.2**	**3.41**	**256.2**	**6.21**	**295.9**	**12.35**	**360.6**
53	8	4	4	10	10	1	**60,824.2**	**157.8**	**3.43**	**199.2**	**6.43**	**232.8**	**12.53**	**284.5**
54	8	4	8	10	10	1	**55,165.4**	**223.1**	**3.29**	**276.5**	**6.18**	**321.6**	**11.87**	**395.8**
55	8	8	4	10	10	1	**56,137.5**	**195.3**	**2.75**	**243.3**	**5.45**	**280.9**	**10.67**	**353.2**
56	8	8	8	10	10	1	**52,106.8**	**238.7**	**2.87**	**299.5**	**5.65**	**345.6**	**10.28**	**432.6**
57	4	4	4	10	10	2	**64,162.8**	**161.6**	**2.76**	**204.9**	**5.26**	**236.2**	**9.89**	**292.5**
58	4	4	8	10	10	2	**59,704.1**	**196.4**	**3.26**	**244.2**	**5.64**	**280.3**	**11.31**	**350.7**
59	4	8	4	10	10	2	**60,873.2**	**185.8**	**3.05**	**228.8**	**5.74**	**264.4**	**10.92**	**327.5**
60	4	8	8	10	10	2	**55,629.5**	**225.3**	**3.52**	**281.6**	**6.51**	**324.6**	**12.29**	**408.5**
61	8	4	4	10	10	2	**62,344.2**	**174.1**	**3.18**	**218.9**	**6.35**	**250.9**	**11.89**	**317.2**
62	8	4	8	10	10	2	**56,548.6**	**240.2**	**3.21**	**304.1**	**5.76**	**351.7**	**10.58**	**435.8**
63	8	8	4	10	10	2%	**57,533.3**	**216.6**	**2.85**	**268.3**	**5.47**	**310.2**	**10.21**	**384.3**
64	8	8	8	10	10	2	**53,408.5**	**261.7**	**2.84**	**329.6**	**5.23**	**380.4**	**10.53**	**470.7**

The best results of new approach

distance. The results reported in Table 6 demonstrated better solutions even with eight Cs, Hs, and MCs rather than four existing health facilities presently operating in Golestan province. The most important result from running the model for the Golestan province is that when the current healthcare system was studied in combination with leading MCs and assigning patients to the nearest MCs, the best solutions were obtained. Because Gorgan and Gonbad-e Kavus cities did not respect OSs and ISs, more MCs had to be established in cities farther away from them to ensure that the minimum service distance was adhered to.

5.3.2 Scenario II

The case problem in the Golestan healthcare network is solved by BICA [42], BGA [43], and BPSO [22]. The parameters of these metaheuristic algorithms are indicated in Table 7. Table 8 reports numerical experiments of solution approaches on the mentioned 64 instances constructed from the case study concerning the accuracy and CPU time. The proposed BICA and BPSO are the best and worst algorithms found in a run, and the objective value is the average of best functions in 30 runs.

The new BICA is the fastest method where its average CPU time is less than BICA [42], BGA [43], and BPSO [22] algorithms. Based on Table 8, the proposed BICA is superior to BICA [42], BGA [43], and BPSO [22] algorithms from the point of view of solution accuracy. By evaluating all the methods utilized in the MHPHN from viewpoints of an average gap, the new BICA provides the most desirable solutions compared to other metaheuristic algorithms in the literature until now.

Table 8 also shows the impact of solution approaches on the efficiency of healthcare networks concerning CPU time with varying p, q, and r values. As seen in Table 8, the CPU time under location operations and p, q, and r values have a rising trend based on the number of locations to be established and services. In addition, by increasing p, q, and r values and referrals, the communications between patients and the health service locations increase considerably.

5.3.3 Scenario III

Sensitivity analysis was performed to allow the designer to realize how changes in θ_1,θ_2 and θ_3 parameters influence model results due to the restraints of data in the case study and the application of past data to evaluate future changes. The results presented in Table 6 indicate solutions by increasing the θ_1,θ_2, and θ_3 parameters from 5%, 5%, and 1% to 10%, 10%, and 2%, respectively. Similar to the scenario I, the numerical results reported in Table 6 offer changes to the locations of health services and the total travel distance.

The θ_1 and θ_2, two important parameters of the MHPHN can affect the health service levels provided to a patient in an C or H. Table 6 shows the change in the total distance from patients to health facilities concerning an increase and decrease in the values of θ_1 and θ_2. As can be noticed, when θ_1 and θ_2 increase, more patients must be served through Cs and, after that, be referred to Hs for OS. Thus, the increase in the objective function is based on the extra distance to meet the DS and OSs.

Following Table 8, the increase in the θ_2 leads to more patient-H travel distance than the θ_1 parameter. Since the Cs cannot meet the need for OSs. Therefore, after receiving DSs, the patients are referred to Hs. So, the objective function increases because of the referral of patients between Cs and Hs. If the patient is assigned to an C or H for PH, they may be referred for DS within the same C and H. Based on this, we find that higher θ_1 the value would cause less increase in travel distance in comparison with θ_2. Thus, when compared with the influence of change θ_1, increases in θ_2 have a stronger influence on the location of Cs and Hs and confirm a substantial increase in the objective value.

Table 8 also demonstrates the impact of increasing θ_3 by 1% and 2%, leading to an increase in the objective value. It is perceived that the total travel distance and the need for ISs increase as θ_3 increases. It is also seen that despite an increase in IS gives rise to an increase in the patient-MC travel distance, increases in ISs do not always give rise to substantial increases in the objective value. This can be clarified by a balance acquired between the travel distance reduction due to the location of new MCs and the influence of more patients traveling due to the ISs increase. So, location decisions and total travel distance were demonstrated to be sensitive to variations in the θ_3 parameter.

5.4 Integrated mathematical approach for healthcare infrastructure on Golestan province

The paper's aim is to motivate development planners to urgently invest in MHME's technical and institutional capability to apply an integrated mathematical approach, to match the rapid expansion of healthcare network in the Golestan province of Iran. To do this, it raises three points:

1. Infrastructure is central to the delivery of the healthcare services. It underpins the socio-economic goals and has impacts on people's health.
2. The proposed approach will allow for the optimization of the benefits and trade-offs of infrastructure development, allowing it to contribute most effectively to the health network in the Golestan province of Iran and the context of existing healthcare facilities.
3. The MHME must act to implement the proposed mathematical model in the Golestan province of Iran, by supporting the development of the necessary technical and institutional capacity at the provincial and national level, building on existing legal instruments, tools, and guidance where possible.

Adopting integrated mathematical approach needs specialized knowledge and technical capacity to adapt and apply the available healthcare facilities in the provincial and regional context. It also needs particular institutional arrangements that support combined top-down and bottom-up processes. Iran National Science Foundation need to enable cooperation between Ministry of Science Research and Technology, MHME, and Ministry of Roads and Urban Development, while allowing for inclusive, transparent, and ongoing stakeholder consultation and public participation to feed into all phases of the healthcare infrastructure development cycle.

The paper recommends three ways that the Iran National Science Foundation can promote the use of integrated mathematical approach to healthcare infrastructure at a network scale:

First, there is a need to make healthcare infrastructure's centrality to the annual agenda, place integrated mathematical approach for healthcare infrastructure on the provincial policy agenda as a distinctive item, to mobilize the research community of the respective ministries in demonstrating the benefits of capacitated, referral, three-level, integrated healthcare infrastructure planning, and to access to the healthcare services with minimum distance to locate new healthcare facilities.

Second, there is a need to merge existing healthcare facilities available for healthcare infrastructure development, analyze and address gaps where existing healthcare facilities are lacking for integrated mathematical approach, and provide guidance for further use of new healthcare facilities in the provincial context. Such an assessment would result in normative and technical guidance for using existing healthcare facilities and mathematical approach in support of different development priorities in provincial context.

Third, there is a need to work together to strengthen the technical and institutional capacity of the Golestan province of Iran with economies in transition to adopt and apply integrated mathematical approach to healthcare infrastructure in support of the annual agenda.

6 Conclusions and future work

We have presented a median hierarchical location-allocation problem on the healthcare network (MHPHN) to assist designers in locating a set of clinics (Cs), hospitals (Hs), and medical centers (MCs) by considering referrals and flows between them for various health services. A mixed-integer linear programming model is developed to minimize the travel distance from patients to health service providers. The application of MHPHN to a real-world case study determined a structure to evaluate and show the practicality of the location model as an adaptable decision-making strategy to help design healthcare networks. So, the new model can efficiently be utilized by planners of the healthcare network of Golestan province in Iran to investigate where to locate new facilities.

A modified version of the binary imperialist competitive algorithm (BICA) is proposed to solve the new model. Two improvement strategies are considered in the BICA structure to enhance the search mechanism and the quality of the solutions to generate better solutions with a better exploration of the MHPHN. The novel model has been implemented using data from the Golestan province of Iran. As demonstrated in Table 8, the computational experiments illustrated that the developed BICA had better performance concerning the accuracy of solutions as compared to BICA [42], binary genetic algorithm (BGA) [43], and binary particle swarm optimization (BPSO) [22]. Additionally, novel BICA achieved higher efficiency in execution time.

In this study, we have selected three scenarios to show the new model's advantage, helpfulness, and behavior. These scenarios report various decision-making strategies to analyze promising improvements to the healthcare network. The proposed model was indicated to provide important information on referrals and flows, on catchment populations of healthcare facilities, and the location of Cs, Hs, and MCs for the healthcare designer.

Regarding future developments, we propose a median hierarchical mixed-integer mathematical formulation that analyzes the reorganization of healthcare networks of Golestan province and the effect of locating health service providers on patient access to health services. Furthermore, it will be interesting to develop other mathematical models to improve the efficiency of the healthcare network. For example, a healthcare network with the minimum number of locations (Set covering location model) and the maximum coverage of patients (Maximum covering location model). Also, it will be essential to extend the current model to consider stochastic or fuzzy data. Alternative metaheuristic algorithms (e.g., simulated annealing, tabu search, and artificial bee colony) can be studied to improve the model efficiency.

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Data availability All data generated or analyzed during this study are included directly in the text of this submitted manuscript. There are no additional external files with datasets.

Declarations

Conflict of interest The author declares that he has no conflicts of interest.

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