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A Scenario-Based Multi-Objective Mathematical Model for the Location-Allocation of Facilities in a Sustainable and Resilient Health Tourism Supply Chain

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ABSTRACT

Objective: Given the rapid expansion of the health tourism industry and the imperative to ensure service continuity under abnormal and disruptive conditions, the design of a supply chain that simultaneously incorporates sustainability and resilience considerations has become critical. This study aims to develop an integrated decision-making framework for the optimal location–allocation of primary and backup facilities within a health tourism supply chain.

Methodology: To this end, a scenario-based multi-objective mathematical model is proposed that concurrently addresses conflicting objectives, including the maximization of overall profitability, sustainability performance (encompassing environmental and social dimensions), resilience and efficiency of network flows, and the minimization of unmet demand. The proposed formulation is structured as a multi-echelon model, wherein, at the first level, sustainability and resilience scores, along with inherent uncertainties in demand, capacity, and potential disruptions, are quantified using the fuzzy Analytic Hierarchy Process (FAHP) and subsequently incorporated into the mathematical model. To solve the model and derive optimal solutions, a normalization-based aggregation approach is employed to transform the multi-objective structure into an equivalent single-objective formulation. The applicability and validity of the proposed model are demonstrated through a real-world case study in the health tourism sector of Qom.

Results: The results indicate that the model is capable of generating balanced and implementable solutions that effectively control costs while ensuring a desirable level of sustainable and resilient performance across various scenarios.

Conclusion: The proposed framework can serve as a robust decision-support tool for managers and policymakers to design supply chain networks that are resilient, cost-efficient, and environmentally sustainable.

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Introduction

Health tourism, as one of the most dynamic and rapidly expanding segments of the global industry, integrates medical services with tourism activities and plays a pivotal role in the economic development of countries (Michael Hall, 2011). Nevertheless, the inherently sensitive and life-critical nature of healthcare services renders this supply chain highly vulnerable to a wide spectrum of disruptions, including natural disasters, pandemics such as COVID-19, and political–economic instabilities (Dmitry Ivanov & Alexandre Dolgui, 2020). Such disruptions may not only lead to service interruptions but can also jeopardize patient safety and undermine the international reputation of destination regions. Consequently, the design of a supply chain network that extends beyond mere cost efficiency while simultaneously ensuring resilience against shocks and adherence to sustainability principles has become a strategic imperative (Sabouhiet al, 2018).

Resilience in supply chains refers to the capability to anticipate, adapt to, and rapidly recover from disruptions (Ivanov, 2022). In parallel, sustainability particularly within the healthcare domain emphasizes minimizing the environmental footprint of operations (e.g., waste management and energy consumption) alongside fulfilling social responsibilities, such as equitable access to healthcare services (Tavana et al, 2020). The integration of these two paradigms presents a complex yet indispensable challenge for both scholars and practitioners. Among the most critical decisions in designing such networks is the location–allocation of backup facilities, which play a vital role in maintaining service continuity, ensuring the storage of essential medicines and equipment, and supporting primary healthcare centers during crises.

Traditional mathematical models for facility location have predominantly focused on single-objective cost minimization, often neglecting the inherent uncertainties of real-world environments and the necessity of addressing multiple, and frequently conflicting, objectives. In contrast, multi-objective optimization enables a balanced trade-off among competing criteria such as cost, resilience, and sustainability (Govindan et al, 2017). Furthermore, scenario-based planning has emerged as a powerful tool for modeling uncertainty in key parameters such as demand, capacity, and disruption intensity (Sabouhi et al., 2018). Despite these advances, the integrated consideration of resilience, sustainability, and uncertainty within a unified decision-making framework for the location of backup facilities in health tourism supply chains remains insufficiently explored in the existing literature.

For instance, while studies such as Ivanov and Dolgui (2020) have extensively addressed supply chain resilience, and Govindan et al. (2017) have investigated sustainability aspects in network design, they have not specifically focused on the health tourism sector, which possesses unique characteristics such as reliance on international patient flows and high time sensitivity.

Similarly, although Tavana et al. (2020) have examined sustainability within tourism contexts, they have not systematically incorporated operational resilience against large-scale disruptions into their location-allocation models. This gap highlights the necessity for developing a comprehensive model that simultaneously captures these dimensions under uncertainty.

In response, the present study seeks to bridge this gap by proposing a scenario-based multi-objective mathematical model. The proposed model pursues three primary objectives: (1) minimizing investment and operational costs, (2) maximizing network resilience through measures such as redundancy and rapid recovery, and (3) maximizing sustainability by incorporating indicators related to emission reduction and local employment generation. To render the multi-objective model tractable, a normalization-based weighting approach is employed, allowing decision-makers to reflect their strategic priorities through the assignment of relative weights to each objective. The output of the model determines the optimal number, location, and allocation domains of backup facilities within the health tourism supply chain network. By providing a quantitative and flexible decision-support framework, this research enables industry stakeholders to design networks that are not only competitive and cost-efficient but also resilient and socially and environmentally responsible.

Theoretical Foundations

Despite its breadth and diversity, tourism lacks a single, universally accepted definition. One of the most widely recognized definitions has been provided by the World Tourism Organization, according to which tourism encompasses the activities of individuals traveling to and staying in places outside their usual environment for less than one year for purposes such as leisure, business, or other motivations. This concept includes a broad spectrum of travel types, including recreational, business, visiting relatives, educational, scientific, sports, medical, and religious trips. In other words, tourism represents an experience that transcends everyday life, guiding individuals into new environments and offering opportunities for exploration, learning, and the acquisition of novel experiences (Khani et al., 2011).

Health tourism, as a sub-sector of the broader tourism industry, refers to the travel of individuals to destinations their place of residence for the purpose of receiving medical treatment or healthcare services (World Tourism Organization, 2019). This form of tourism involves individuals who, in addition to utilizing conventional tourism services, seek medical care or specialized therapeutic interventions (Nikraftar & Hosseini, 2017). The primary objective of such travel is to enhance health, prevent disease, and obtain treatment. Health tourism plays a significant role in job creation, revenue generation, infrastructure development, improvement of public health, and the exchange of knowledge and culture (UNWTO, 2019). Broadly, this domain can be categorized into two main segments: wellness tourism and medical tourism (Asadi & Daryaei, 2011). Distinguishing between these segments is essential for a proper understanding of the health tourism value chain, as each exhibits distinct needs, motivations, and target markets.

Medical tourism, as a subset of health tourism, focuses on the provision of specialized and often complex medical services (Gössling et al., 2012). It encompasses a range of activities in which individuals travel frequently across long distances or international borders—to receive medical treatment, sometimes in combination with leisure or business purposes (Global Spa Summit, 2011). In essence, medical tourism involves travel outside one's usual environment, for a period not exceeding one year, with the aim of restoring physical and psychological well-being. In contrast, wellness tourism emphasizes the enhancement of health and well-being through activities such as hydrotherapy, yoga, and meditation (Shalbafian, 2015). This type of tourism adopts a preventive and proactive approach to maintaining and improving a healthy lifestyle and is often associated with concepts such as relaxation, rejuvenation, and holistic balance. Supply chain management refers to a set of approaches aimed at effectively integrating suppliers, manufacturers, warehouses, and retailers to ensure that required products are delivered to customers at the right time and place, with minimal cost and a high level of service (Etemadi & Kasraei, 2020). In the context of health tourism, an efficient supply chain must coordinate a complex network of service providers including accommodation, medical, recreational, and support services to deliver a seamless and high-quality experience for tourists. The concept of a sustainable supply chain extends beyond mere efficiency, emphasizing the management of material, information, and financial flows in a manner that simultaneously satisfies economic, environmental, and social objectives arising from customer needs and stakeholder expectations (Khalili et al., 2022).

Within this framework, sustainability in the health tourism supply chain not only contributes to improving service quality and attracting more tourists but also plays a crucial role in preserving the natural and cultural resources of destinations and enhancing the well-being of local communities. The implementation of an integrated sustainability strategy across all stages of the supply chain from the procurement of medical equipment to waste management and the empowerment of local communities is therefore essential for the long-term success and competitiveness of health tourism destinations.

Uncertainty stemming from dynamic environmental changes, the inability to accurately predict their impacts, and the difficulty of estimating the consequences of responsive actions (Hindijani et al., 2020) constitutes one of the fundamental challenges in modern supply chain management. Such uncertainty may manifest in various forms, including simultaneous shocks to supply and demand, exchange rate volatility, regulatory changes, and natural disasters.

Within the health tourism supply chain, factors such as seasonal demand fluctuations, shifts in visa policies, pandemics like COVID-19, and political instability can generate significant levels of uncertainty. To effectively cope with these challenges and maintain desirable performance levels, organizations must adopt resilience-oriented strategies. Supply chain resilience refers to the capability to anticipate, prepare for, respond to, and recover from unexpected disruptions, while returning to a stable state—or even achieving a superior post-disruption condition. This capability can be enhanced through strategies such as diversification of supply sources, establishment of backup capacities, deployment of advanced analytical technologies (e.g., artificial intelligence) for forecasting and scenario simulation, and the strengthening of regional and global collaborations.

Literature Background

Research in the field of health tourism has undergone a remarkable evolution over time. In its early stages, the primary focus was on demand analysis and tourist behavior; this gradually shifted toward destination development and promotion, and in recent years, scholarly attention has increasingly centered on policy implications, outcomes, and sustainability issues within the industry. Key determinants influencing the attraction of health tourists include accessibility of services, diversity of treatment options, quality of facilities, travel planning, safety, and governmental support mechanisms. Furthermore, in the context of destination development, issues such as child vaccination, oral and dental health, legal frameworks, evaluation systems, and macro-level policy design require particular attention (Zhong et al., 2021).

Classification of Health Tourism Studies

Andrés de la Hoz-Correa et al. (2018), through a systematic review of the literature, categorized health tourism research into six principal domains:

(1) ethical issues, trust, and accreditation;
(2) health, wellness, spa tourism, and service quality;
(3) specialized medical and healthcare topics;
(4) sensitive practices in medical tourism;
(5) destination marketing in medical tourism; and
(6) globalization, policy, and impacts on international patients.

A substantial proportion of studies in this field has concentrated on marketing-related aspects such as consumer behavior, destination image, and information sources, as well as cultural and psychological dimensions.

Supply Chain and Mathematical Modeling Studies

In recent years, increasing attention has been directed toward supply chain management within the health tourism domain. Ahmadi Moghaddam et al. (2019) developed a mathematical model for the dental tourism supply chain across six cities in Mazandaran Province, conceptualizing tourists, medical centers, and accommodation facilities as the three core components, with the objective of profit maximization through optimal allocation. In a subsequent study, Ahmadi Moghaddam et al. (2021) employed a hybrid DANP–VIKOR approach to prioritize potential locations for investment in dental tourism. Hosseini et al. (2021), focusing on the impacts of COVID-19 on ecotourism, proposed a bi-objective fuzzy mathematical model aimed at cost reduction and customer satisfaction enhancement. Nasrabadi and Mohammadi Pour (2021) identified risks in the health tourism supply chain through a meta-synthesis approach and modeled their interrelationships using interpretive structural modeling (ISM). Subsequently, Majroudi Nasrabadi (2022) utilized fuzzy cognitive mapping to identify and model key success factors of supply chain resilience across four distinct stages. In a related contribution, Majroudi Nasrabadi and Mohammadi Pour (2022) developed a conceptual model of critical success factors for enhancing supply chain resilience using the ISM approach.

Zavari et al. (2022), through in-depth interviews, proposed a model for improving collaboration within the medical tourism supply chain. Dinkusong et al. (2023) analyzed supply chain barriers using mathematical modeling and open innovation approaches, offering solutions to enhance collaboration and profitability. Similarly, Shokri Garjan et al. (2023) examined the effects of pricing strategies (e.g., discounts) and service quality on customer attraction through optimization techniques. Pach (2023) introduced a mathematical model for assigning recreational activities to medical tourists under medical, temporal, and budget constraints, with the objective of maximizing both tourist satisfaction and industry profitability. Kazakov et al. (2023) investigated logistics management in health and tourism centers, emphasizing the role of digital infrastructure. Cerati et al. (2024) proposed a mathematical model for the design of a sustainable dental tourism supply chain, incorporating waste management considerations and optimizing the location of treatment facilities and recycling centers. Finally, Babaei et al. (2024), focusing on social aspects and uncertainty conditions induced by the COVID-19 pandemic, developed a two-stage framework for supplier evaluation and resilience enhancement in the medical tourism supply chain, integrating fuzzy DEMATEL–ANP with goal programming.

Studies on Tourist Behavior, Marketing, and Service Quality

Chun-Hung Lin (2014) examined the influence of culinary experiences and psychological well-being on tourists' revisit intentions in hot spring destinations. Kampon Kru et al. (2020), employing structural equation modeling (SEM), analyzed the effects of water-based tourism experiences on quality of life, satisfaction, and tourist loyalty. Similarly, Po et al. (2021) investigated the impact of subjective knowledge and health awareness on post-pandemic health tourism intentions particularly in the aftermath of COVID-19 using hierarchical regression and SEM techniques. Zheng Liao et al. (2023) explored the role of reference group influence on young individuals' intentions toward health tourism. Qiang Ge and Ying Chen (2024) examined tourist satisfaction and behavioral intentions in eco-health tourism through structural equation modeling. Ali Turkzadeh et al. (2024), in two complementary studies, first compared alternative market segmentation methods in the health tourism industry and subsequently proposed a value-based segmentation of the West Asian medical tourism market, with a particular focus on Iran.

Studies on Sustainability, Policy, and Destination Development

Azam et al. (2018) investigated the impact of tourism activities on CO_2 emissions across three Southeast Asian countries Malaysia, Singapore, and Thailand. Yu et al. (2019) reviewed sustainability challenges faced by non-profit organizations in the health tourism sector in South Africa. Perkumienė et al. (2019) analyzed collaborative perspectives in sustainable medical tourism, focusing on Lithuania. Butler and Szromek (2019) examined the concept of value proposition within business models of health tourism enterprises.

Asadi et al. (2020), using the Delphi method, identified key factors influencing health tourism development in Yazd. Bayuo et al. (2020) explored the role of digital marketing as an innovative communication tool within the health tourism ecosystem. Büyüközkan et al. (2021) applied a hybrid SWOT–AHP–MABAC fuzzy approach to select optimal health tourism strategies in Istanbul. Kaewkitipong et al. (2021) investigated determinants of vaccine tourism in the context of COVID-19. Hong Zhang et al. (2021) analyzed health tourism destinations as therapeutic landscapes and their influence on health perceptions among elderly seasonal migrants in China. Tleukhanov et al. (2021) explored development prospects for health tourism in Lake Ray, Kazakhstan. Xiang et al. (2022) examined the diverse demand for health tourism from an intra-industry trade perspective in China. Gądełska et al. (2023) compared determinants influencing the choice of spa resorts among employed and retired Polish health seekers. Ridderstaat (2023) analyzed latent demand and pricing behavior in outbound health tourism from the United States. Bagheri et al. (2023), using the Best–Worst Method (BWM), prioritized medical tourism development strategies in Iran. HamzehPour et al. (2023) investigated safe acceptance in culturally competent nursing care for medical tourists in Iran. Mihăilă et al. (2024) conducted a bioclimatic assessment of sustainable tourism activities in regions of Romania. Teskouras et al. (2024) examined sustainable medical tourism in Central Macedonia, Greece, through a systematic review combined with empirical research. Ding (2024) analyzed tourist preferences for sustainable hot spring tourism in the post-COVID era in Colorado.

Review and Comparative Studies

Melanie Smith and László Puczkó (2015) examined health tourism and its subdomains, including wellness tourism and spa-based tourism. Melanie Smith (2015) also identified common and unique resources across Baltic countries in the context of health tourism. Jinsoo Lee and Hyeong Lee (2019) developed a health tourism destination index using an advanced Analytic Hierarchy Process (AHP). Li Yan and Ying He (2020), applying actor-network theory, explored the co-evolution of therapeutic landscapes and health tourism in Bama villages, China. Salehi Esfahani et al. (2021) examined the impact of tourism demand on health tourism expenditures in Canada. Mojarradi et al. (2021), through field studies and SWOT–QSPM analysis, developed a strategic plan for the health tourism supply chain in Razavi Hospital, Mashhad. Finally, Liang Zhong et al. (2021), through a comprehensive literature review spanning 1970–2020, identified three primary dimensions in health tourism research: market dynamics, destination development, and environmental context.

Materials and Methods

The present study adopts a two-level hybrid qualitative–quantitative approach to develop a comprehensive decision-making framework for the location–allocation problem of backup facilities within the health tourism supply chain. Given the inherent complexity of the problem characterized by multiple conflicting objectives (cost, resilience, and sustainability) and environmental uncertainties the use of an integrated methodological framework is both necessary and justified.

At the first level, a qualitative–survey-based approach is employed to collect the data required for parameterization and weighting of the mathematical model. This stage is grounded in the Fuzzy Analytic Hierarchy Process (FAHP), which is specifically designed to structure imprecise and linguistic judgments provided by experts in the domains of health tourism, supply chain management, and crisis management. Through the formation of an expert panel and the distribution of pairwise comparison questionnaires, the final weights of key resilience criteria (e.g., recovery capability and redundancy) and sustainability dimensions (including economic, social, and environmental aspects), as well as the probabilities associated with various disruption scenarios, are determined. The rationale for employing this method lies in its capability to effectively handle ambiguity inherent in forecasting future events and evaluating qualitative criteria. The output of this stage is the transformation of tacit and experiential expert knowledge into quantified and structured data, which serve as essential inputs for the second level.

The second level of the research is fully quantitative and model-driven. At this stage, using both secondary data sources (e.g., cost statistics, distances, and capacity data) and the outputs obtained from the first level, a scenario-based multi-objective mathematical model is developed.

The model simultaneously pursues three primary objective functions: maximizing the expected profitability of the network, maximizing overall resilience and sustainability, and maximizing network efficiency. The adoption of a scenario-based approach enables the incorporation of uncertainty in critical parameters such as demand levels and the extent of facility disruptions, thereby enhancing the model's alignment with the dynamic nature of real-world environments.

Given that these objectives are inherently conflicting (for instance, increasing resilience often entails higher investment costs), it is not feasible to identify a single solution that optimizes all objectives simultaneously. Therefore, to solve the model and obtain a compromise optimal solution, a normalization-based weighted aggregation method is employed. The rationale for selecting this solution approach lies in its transparency and flexibility. Initially, each objective function is optimized independently to determine its feasible range (from ideal to anti-ideal values). Subsequently, through a linear normalization process, the values of objective functions—despite having different measurement units (e.g., monetary units versus performance scores)—are transformed into dimensionless values within the interval [0,1], enabling meaningful comparison and aggregation. Finally, a single composite objective function is constructed as a linear combination of the normalized objectives, weighted according to their relative importance. These weights, which can reflect the strategic preferences of decision-makers (derived from the first-level analysis), determine the contribution of each objective to the final solution.

Solving the resulting single-objective model yields a practical and efficient solution that establishes a transparent trade-off among competing objectives. In summary, the integration of these two interconnected levels effectively combines qualitative expert judgment with the rigor and precision of mathematical modeling, resulting in a framework that is both scientifically robust and practically applicable within real-world environments characterized by complexity and uncertainty.

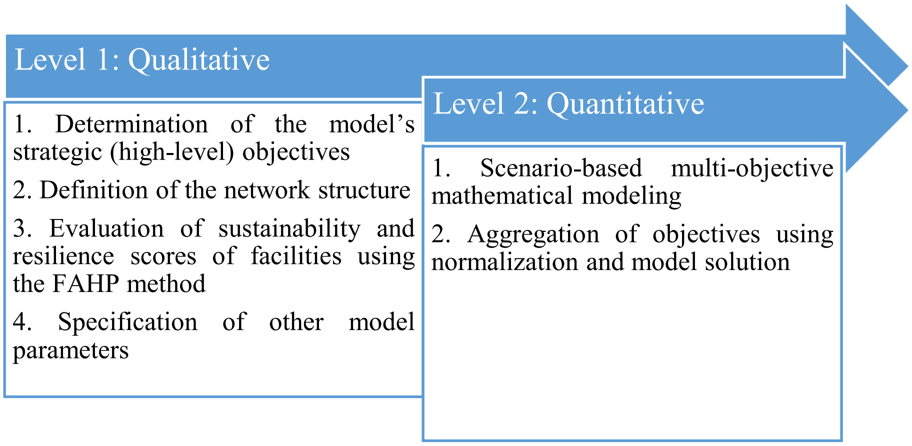

Figure 1. Research methodology based on a two-level approach

Problem Description

One of the main shortcomings of previous studies is the insufficient consideration of sustainability dimensions within transportation systems and inter-facility flow structures. In the present research, the optimization of sustainable flows is treated as a fundamental component of the model, incorporating objectives such as carbon emission reduction, energy consumption management, and mitigation of urban traffic congestion. This integrated perspective enriches the proposed model from both environmental and social sustainability viewpoints.

Moreover, in the model developed by Babaei, Sazvar, Niri, and Tavakoli-Moghadam (2024), there is an excessive emphasis on visa issuance and its associated costs, as well as marketing-related aspects. However, visa processing represents only one of many services required by health tourists. Such a narrow focus may lead to the neglect of other critical components within the health tourism supply chain. To address this limitation, the present study introduces a Centralized Service Management Hub, which acts as a coordinating entity for all service categories including medical, accommodation, recreational, transportation, and administrative services. This integration enhances coordination across the entire health tourism supply chain, improves operational efficiency, and significantly elevates the overall experience of health tourists. This study proposes a multi-objective optimization model aimed at maximizing stakeholder profit, customer satisfaction, and supplier performance. To address the uncertainty inherent in real-world environments, a scenario-based model integrated with fuzzy parameters is developed for the first time in this context.

Main Contributions of the Study

The key innovations of this research are summarized as follows:

- Design of a novel health tourism supply chain consisting of three main operational nodes (medical, accommodation, and wellness services) and one centralized service management and support node.
- Introduction of a Health Tourism Service Management Hub for the first time, responsible for coordinating and integrating support services.
- Modeling and optimization of sustainable flows within the main network structure.
- Development of a linear multi-objective mixed-integer mathematical programming model for the proposed supply chain network.
- Incorporation of service-level resilience analysis as a two-stage framework.
- Integration of diverse service categories (medical treatment, wellness, recreational, and auxiliary services) within the research scope.

- Evaluation and selection of healthcare service suppliers based on lean management and sustainability principles.
- Inclusion of social and environmental considerations within objective functions, constraints, and initial facility selection.
- Introduction of a two-stage supplier evaluation process for medical services as a preliminary step, combining multi-criteria decision-making (MCDM) techniques with multi-objective programming.

Therefore, the final network is structured as follows:

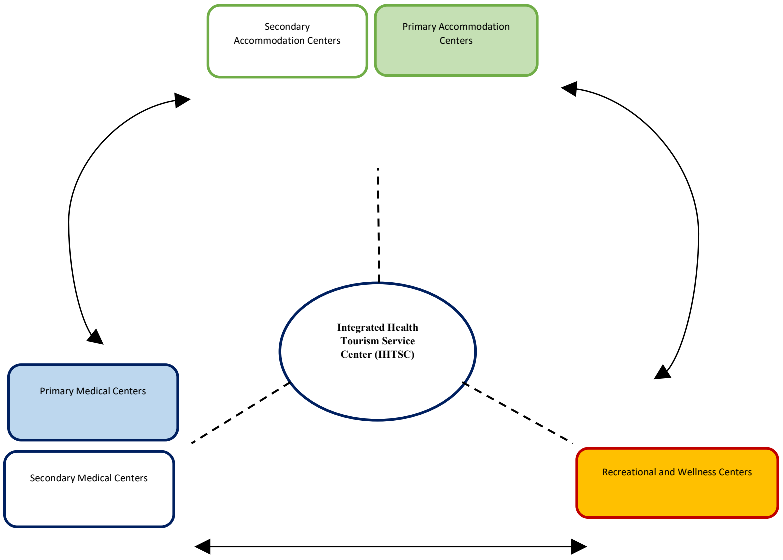

Figure 2. Health Tourism Supply Chain Network

Integration of Fuzzy Analytic Hierarchy Process and Multi-Objective Mathematical Modeling

In complex and strategic problems such as the design of a health tourism supply chain network, decision-making based solely on quantitative data or expert intuition leads to unbalanced and unreliable outcomes. To address this challenge, the present study adopts a two-stage framework consisting of a qualitative approach based on the Fuzzy Analytic Hierarchy Process (FAHP) and a quantitative approach based on multi-objective mathematical modeling. The integration of these two approaches enables the simultaneous consideration of both subjective and objective criteria, thereby enhancing the theoretical rigor and analytical robustness of the final results. The innovative aspect of this research lies in the application of fuzzy logic combined with the Analytic Hierarchy Process (FAHP), a methodology widely recommended in the literature for evaluating sustainability and resilience dimensions. The necessity of employing FAHP arises from the inherently multi-criteria and uncertain nature of concepts such as sustainability and resilience. In strategic decision-making problems, such as health tourism network design, criteria like “social responsibility” or “reliability under crisis conditions” cannot be accurately quantified using crisp numerical values.

Classical methods such as traditional AHP are unable to adequately handle the ambiguity embedded in linguistic expert judgments and often introduce artificial precision. In contrast, fuzzy logic allows the modeling of linguistic variables (e.g., “very important,” “highly significant”), thereby preserving uncertainty within the decision-making process and generating more realistic input data for the mathematical model. Consequently, the final output is supported by a stronger theoretical and analytical foundation.

The FAHP procedure is implemented using triangular fuzzy numbers. First, the hierarchical structure of criteria and alternatives is established, and expert judgments are collected in linguistic form. These linguistic evaluations are then converted into triangular fuzzy numbers such as:

$$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$$

where l_{ij}, m_{ij}, and u_{ij}represent the lower bound, most likely value, and upper bound of the judgment, respectively. Subsequently, fuzzy weights for each criterion are computed using the fuzzy geometric mean method.

$$\widetilde{w}_i = \left(\prod_{j=1}^{n} \tilde{a}_{ij} \right)^{1/n}$$

Finally, the fuzzy weights are defuzzified using methods such as the Center of Area (COA) approach and converted into crisp values for integration into the mathematical model (e.g., as sustainability parameters $Sc_h$and Sc_m). This systematic procedure transforms qualitative expert judgments into reliable quantitative inputs for multi-objective optimization.

Mathematical Model Development

This study aims to formulate a multi-objective decision-making framework for health tourism supply chain design by capturing four key and sometimes conflicting dimensions of system performance. The first objective (economic) focuses on minimizing the net cost, including both setup and operational costs relative to generated revenues, thereby ensuring the financial sustainability of the system. The second objective (sustainability) seeks to maximize the average sustainability score of active facilities, ensuring environmental and social responsibility across the network. The third objective (resilient efficiency) aims to maximize the weighted service coverage ratio relative to travel time, enabling rapid access to high-quality services even under disruptive conditions. The fourth objective (demand non-coverage minimization) incorporates penalties for unmet demand into the objective function, encouraging the model to satisfy customer needs as fully as possible.

This integrated framework, by combining qualitative assessments with quantitative optimization, yields a design that is not only economically viable but also aligned with sustainable development principles and capable of maintaining performance and resilience across various scenarios. The objectives of this study can be classified into two categories: intrinsic (existential) objectives and functional objectives. Intrinsic objectives represent the standalone performance of facilities, such as cost or resilience and sustainability scores. In contrast, functional objectives emphasize the behavior of facilities within the system, their interactions with other nodes, and the flows between them, focusing on network dynamics rather than isolated performance indicators.

Assumptions of the Mathematical Model

In the mathematical modeling of the health tourism supply chain in Qom under sustainability and resilience considerations, a set of realistic assumptions is adopted to balance scientific rigor with computational tractability. These assumptions are designed to focus on strategic decision-making elements such as facility location and resource allocation.

Accordingly, the transportation network is simplified by assuming a single optimal route between facilities, and the existence of multiple alternative paths is not considered. Moreover, since the type of transportation mode is not a critical determinant at the strategic planning level, heterogeneity in transportation fleets is ignored, and transportation costs are calculated using an average value. The Integrated Health Tourism Service Center (IHTSC) is modeled as a virtual coordination node with non-physical interactions, allowing its role in service integration to be evaluated independently of geographical distance. However, the model remains flexible, and this node can be extended to a physical location if required in future developments.

Given the high sensitivity of medical and accommodation services in health tourism and the importance of resilience in these sectors under crisis conditions, backup facilities with excess capacity are considered only for these two service types. These backup centers ensure service continuity in case of disruptions affecting primary facilities.

Regarding demand and capacity, the amount of service provided is assumed to be equal to the available capacity, which may not necessarily match total demand due to inherent capacity limitations that restrict full demand satisfaction. The capacity of each facility is defined based on minimum resource requirements, including equipment, personnel, and raw materials, in order to prevent system bottlenecks.

Traffic congestion is incorporated as a key sustainability factor through traffic coefficients assigned to different routes. For instance, central urban areas, despite shorter distances, may experience higher congestion levels, which directly affects travel time, fuel consumption, emission levels, and ultimately tourist satisfaction.

Unmet demand is considered to arise from two main sources: capacity limitations and facility disruptions under different scenarios, both of which are explicitly modeled within the scenario-based framework. Facility activation costs include all setup expenditures such as equipment procurement, construction or leasing, and workforce recruitment, while the profitability of each facility is defined as the difference between its operational revenue and operating costs.

Finally, all decision variables are defined as functions of tourist type, service category, different scenarios (ranging from normal to critical conditions), and planning periods. This structure ensures that the model is capable of capturing diverse operational conditions and providing optimal solutions under varying environmental and disruption states.

Sets and Indices

The mathematical model is defined over the following sets and indices:

i={1,2,…,l}	types of accommodation services
j={1,2,…,l}	types of medical services
K={1,2,…,k}	types of recreational and wellness services
L={1,2,…,l}	types of support and non-physical services
G={1,2,…,g}	customer types (health tourists)
M={1,2,…,m}	primary medical centers
M’={1,2,…,m’}	secondary (backup) medical centers
H={1,2,…,h}	accommodation centers and hotels
H’={1,2,…,h’}	secondary (backup) accommodation centers
R={1,2,…,r}	recreational and wellness centers (other services)
U={1,2,…,u}	Integrated Health Tourism Service Center (IHTSC)
T={1,2,…,t}	planning time periods
S={1,2,…,s}	Scenarios
Q={1,2,…,q}	service quality / facility equipment levels
C={1,2,…,c}	sustainability and resilience criteria

Parameters

Cost Parameters

$A1_{\mathrm{hq}}$	Fixed activation cost of primary accommodation center $h$at quality level q
$A'1_{h'q}$	Fixed activation cost of backup accommodation center h'at quality level q
$A2_{mq}$	Fixed activation cost of primary medical center $m$at quality level q
$A'2_{m'q}$	Fixed activation cost of backup medical center m'at quality level q
$A3_{rq}$	Fixed activation cost of recreational and wellness center $r$at quality level q
$A4_{u}$	Fixed activation cost of the Integrated Health Tourism Service Center (IHTSC) u
AO	Transportation cost based on time
$P1_{iq}$	Profit per unit of accommodation service $i$at quality level q
$P2_{jq}$	Profit per unit of medical service $j$at quality level q
$P3_{kq}$	Profit per unit of recreational service $k$at quality level q
$P4_{lq}$	Profit per unit of support/non-physical service $l$at quality level q

Demand Parameters

$D1_{\mathrm{giq}}$	Demand of tourist group g for accommodation service $i$at quality level q
$D2_{\mathrm{gjq}}$	Demand of tourist group g for medical service $j$at quality level q
$D3_{\mathrm{gkq}}$	Demand of tourist group g for recreational service $k$at quality level q

Capacity Parameters

$CAP1_{h'iq}$	Capacity of backup accommodation center h' for service $i$at quality level q
$CAP2_{m'jq}$	Capacity of backup medical center $m'$for service j at quality level q
$CAP4_{ulq}$	Capacity of integrated service center $u$for support service l at quality level q
$CAP1_{hiq}$	Capacity of primary accommodation center h for service $i$at quality level q
$CAP2_{mjq}$	Capacity of primary medical center $m$for service j at quality level q
$CAP3_{rkq}$	Capacity of recreational center $r$for service k at quality level q

Distance Parameters (Time-based with traffic effects)

$O11_{\mathrm{hm}}$	Travel time between accommodation center h and medical center m
$O12_{hm'}$	Travel time between accommodation center h and backup medical center m'
$O13_{h'm}$	Travel time between backup accommodation center h' and medical center m
$O14_{h'm'}$	Travel time between backup accommodation center h' and backup medical center m'
$O21_{\mathrm{hr}}$	Travel time between accommodation center h and recreational center r
$O22_{\mathrm{h'r}}$	Travel time between backup accommodation center $h'$and recreational center r
$O31_{mr}$	Travel time between medical center $m$and recreational center r
$O32_{m'r}$	Travel time between backup medical center $m'$and recreational center r
CDH	Minimum travel time constraint between accommodation and recreational centers
CDM	Minimum travel time constraint between medical and recreational centers

Other Parameters

$\mathrm{PH}_{\mathrm{hst}}$	Available capacity ratio of accommodation center h under scenario s in period t
$\mathrm{PM}_{\mathrm{mst}}$	Available capacity ratio of medical center m under scenario s in period t
$\mathrm{PR}_{\mathrm{rst}}$	Available capacity ratio of recreational center r under scenario s in period t
$\mathrm{PH'}_{\mathrm{h'st}}$	Available capacity ratio of backup accommodation center h'
$\mathrm{PM'}_{\mathrm{m'st}}$	Available capacity ratio of backup medical center m'
M	A sufficiently large positive number
L	A very small positive number (near zero)
P_{st}	Probability of scenario $s$in time period t
wi_{gi}	Importance of satisfying accommodation demand for tourist g
wj_{gj}	Importance of satisfying medical demand for tourist g
wk_{gk}	Importance of satisfying recreational demand for tourist g
Sc_h	Sustainability and resilience score of accommodation center h
Sc_m	Sustainability and resilience score of medical center m
Sc_r	Sustainability and resilience score of recreational center r
Sc_u	Sustainability score of integrated service center u
α_1	Traffic repetition coefficient (medical–accommodation route)
α_3	Traffic repetition coefficient (medical–recreational route)
α_2	Traffic repetition coefficient (accommodation–recreational route)

UH	Required support services per unit of accommodation service
UM	Required support services per unit of medical service
UR	Required support services per unit of recreational service
HM_{ij}	Accommodation service requirement per unit of medical service
HR_{ik}	Recreational service requirement per unit of accommodation service
MR_{jk}	Recreational service requirement per unit of medical service

Decision Variables

Facility Location Variables

$\boldsymbol{X1_{hq}}$	1 if accommodation center $\boldsymbol{h}$at quality level $\boldsymbol{q}$ is opened; otherwise 0
$X1_{h'q}$	1 if backup accommodation center $\boldsymbol{h'}$ is opened; otherwise 0
$X2_{mq}$	1 if medical center $\boldsymbol{m}$ is opened; otherwise 0
$X2_{m'q}$	1 if backup medical center $\boldsymbol{m'}$ is opened; otherwise 0
$X3_{rq}$	1 if recreational center $\boldsymbol{r}$ is opened; otherwise 0
$X4_{uq}$	1 if integrated service center $\boldsymbol{u}$ is opened; otherwise 0

Service Allocation Variables

$Z1_{iqghst}$	Number of accommodation services i provided to tourist group g in center h
$Z'1_{iqgh'st}$	Same for backup accommodation center h'
$Z2_{jqgmst}$	Medical services j provided in center m
$Z'2_{jqgm'st}$	Medical services in backup center m'
$Z3_{kqgrst}$	Recreational services k in center r
$Z4_{lqgust}$	Support services l in integrated center u

Service Flow Variables

$V11_{hmgst}$	Flow from accommodation h to medical m
$V12_{hm'gst}$	Flow from accommodation h to medical m'
$V13_{h'mgst}$	Flow from backup accommodation $h'$to medical m
$V14_{h'm'gst}$	Flow from backup accommodation $h'$to medical m'
$V21_{hrgst}$	Flow from accommodation $h$to recreational r
$V22_{h'rgst}$	Flow from backup accommodation $h'$to recreational r
$V31_{mrgst}$	Flow from medical m to recreational r
$V32_{m'rgst}$	Flow from medical $m'$to recreational r

Shortage Variables

$\mathrm{SQ1}_{\mathrm{gsiq}}$	Shortage of accommodation service i
$\mathrm{SQ2}_{\mathrm{gsjq}}$	Shortage of medical service j
$\mathrm{SQ3}_{\mathrm{gskq}}$	Shortage of recreational service k

Objective Functions

Objective Function 1: Maximization of the Profit from Facility Activation

$$\begin{aligned}
\max f1 = \sum_{s}\sum_{t} P_{st}\Bigg[&\sum_{i}\sum_{g} \mathrm{P1}_{\mathrm{iq}} * (\mathrm{Z1}_{\mathrm{ighst}} + \mathrm{Z'1}_{\mathrm{igh'st}}) \\
&+ \sum_{j}\sum_{g} \mathrm{P2}_{\mathrm{jq}} * (\mathrm{Z2}_{\mathrm{jg}mst} + \mathrm{Z'2}_{\mathrm{jgm'st}}) + \sum_{k}\sum_{g} \mathrm{P3}_{\mathrm{kq}} * \mathrm{Z3}_{\mathrm{kgrst}} + \sum_{l}\sum_{g} \mathrm{P4}_{\mathrm{lq}} * \mathrm{Z4}_{\mathrm{lgrst}}\Bigg] \\
&- \Bigg[\sum_{h}\sum_{q} \mathrm{A1}_{\mathrm{hq}}\,\mathrm{X1}_{\mathrm{hq}} \\
&+ \sum_{h'}\sum_{q} \mathrm{A'1}_{\mathrm{h'q}}\,\mathrm{X'1}_{\mathrm{h'q}} \\
&+ \sum_{m}\sum_{q} \mathrm{A2}_{\mathrm{mq}}\,\mathrm{X2}_{\mathrm{mq}} + \sum_{m}\sum_{q} \mathrm{A'2}_{\mathrm{m'q}}\,\mathrm{X'2}_{\mathrm{m'q}} \sum_{r}\sum_{q} \mathrm{A3}_{\mathrm{rq}}\,\mathrm{X3}_{\mathrm{rq}} + \sum_{u}\sum_{q} \mathrm{A4}_{\mathrm{uq}}\,\mathrm{X4}_{\mathrm{uq}}\Bigg] \\
&- \sum_{t}\sum_{s}\sum_{g} P_{st}.\,AO.\Bigg[\sum_{h}\sum_{m} \alpha_1 O11_{\mathrm{hm}}\mathrm{V11}_{\mathrm{hmgst}} + \sum_{h'}\sum_{m} \alpha_1 O13_{\mathrm{h'm}}\mathrm{V13}_{\mathrm{h'mgst}} \\
&+ \sum_{h}\sum_{r} \alpha_2 O21_{\mathrm{hr}}\mathrm{V21}_{\mathrm{hrgst}} + \sum_{h'}\sum_{r} \alpha_2 O22_{\mathrm{h'r}}\mathrm{V22}_{\mathrm{h'rgst}} + \sum_{m'}\sum_{h} \alpha_1 O12_{\mathrm{m'h}}\mathrm{V12}_{\mathrm{m'hgst}} \\
&+ \sum_{m'}\sum_{h'} \alpha_1 O14'_{\mathrm{m'h'}}\mathrm{V14'}_{\mathrm{m'h'gst}} + \sum_{m}\sum_{r} \alpha_3 O31_{\mathrm{mr}}\mathrm{V31}_{\mathrm{mrgst}} + \sum_{m'}\sum_{r} \alpha_3 O32_{\mathrm{m'r}}\mathrm{V32}_{\mathrm{m'rgst}}\Bigg]
\end{aligned} \tag{1}$$

Objective Function 2: Maximization of the Resilience and Sustainability Score (Environmental–Social) of Facilities

$$\begin{aligned}
max\ f2 = &\sum_{h}\sum_{q} Sc1_{\mathrm{h}}\mathrm{X1}_{\mathrm{hq}} + \sum_{m}\sum_{q} Sc2_{\mathrm{m}}\mathrm{X2}_{\mathrm{mq}} + \sum_{h}\sum_{q} Sc'1_{\mathrm{h'}}\mathrm{X'1}_{\mathrm{h'q}} + \sum_{m}\sum_{q} Sc'2_{\mathrm{m'}}\mathrm{X'2}_{\mathrm{m'q}} + \sum_{r}\sum_{q} Sc3_{\mathrm{r}}\,\mathrm{X3}_{\mathrm{rq}} \\
&+ \sum_{u}\sum_{q} Sc3_{\mathrm{u}}\,\mathrm{X4}_{\mathrm{uq}}
\end{aligned} \tag{2}$$

Objective Function 3: Efficiency of Qualitative and Resilience Flows

$$\begin{aligned}\max f3 = \sum_{s}\sum_{t}\sum_{g} P_{st}(& \frac{\boldsymbol{wi}_{ig}\boldsymbol{wj}_{jg}(\mathrm{PH_{hst}}.\mathrm{PM_{mst}}).\mathrm{V11_{hmgst}}}{O11_{\mathrm{hm}}} + \frac{\boldsymbol{wi}_{ig}\boldsymbol{wj}_{jg}(\mathrm{PH'}'_{\mathrm{h'st}}.\mathrm{PM_{mst}}).\mathrm{V13_{h'mgst}}}{O13_{\mathrm{h'm}}} \\ & + \frac{\boldsymbol{wi}_{ig}\boldsymbol{wj}_{jg}(\mathrm{PH_{hst}}.\mathrm{PM}'_{\mathrm{m'st}}).\mathrm{V12_{hm'gst}}}{O12_{\mathrm{m'h}}} + \frac{\boldsymbol{wi}_{ig}\boldsymbol{wj}_{jg}(\mathrm{PH'}'_{\mathrm{h'st}}.\mathrm{PM}'_{\mathrm{m'st}}).\mathrm{V14_{h'm'gst}}}{O14_{\mathrm{h'm'}}} \\ & + \frac{\boldsymbol{wi}_{ig}\boldsymbol{wk}_{kg}(\mathrm{PH_{hst}}.\mathrm{PR_{rst}}).\mathrm{V21_{hrgst}}}{O21_{\mathrm{hr}}} + \frac{\boldsymbol{wi}_{ig}\boldsymbol{wk}_{kg}(\mathrm{PH'}'_{\mathrm{h'st}}.\mathrm{PR_{rst}}).\mathrm{V22_{h'rgst}}}{O22_{\mathrm{h'r}}} \\ & + \frac{\boldsymbol{wj}_{jg}\boldsymbol{wk}_{kg}(\mathrm{PM_{mst}}.\mathrm{PR_{rst}}).\mathrm{V31_{mrgst}}}{O31_{\mathrm{mr}}} + \frac{\boldsymbol{wj}_{jg}\boldsymbol{wk}_{kg}(\mathrm{PM'}'_{\mathrm{mst}}.\mathrm{PR_{rst}}).\mathrm{V32_{m'rgst}}}{O32_{\mathrm{m'r}}}\end{aligned} \tag{3}$$

Objective Function 4: Minimization of Demand Coverage Shortage

$$\begin{aligned} maxf4 = & \sum_{s}\sum_{t}\sum_{g}\sum_{i}\sum_{q}\left(P_{st}.SQ1_{gsiq}.wi_{ig}\right) \\ & + \sum_{s}\sum_{t}\sum_{g}\sum_{j}\sum_{q}\left(P_{st}.SQ2_{gsjq}.wj_{jg}\right) + \sum_{s}\sum_{t}\sum_{g}\sum_{k}\sum_{q}\left(P_{st}.SQ3_{gskq}.wk_{kg}\right)\end{aligned} \tag{4}$$

Constraints

Constraint of Total Demand Satisfaction (5-7)

$$\sum_{h} Z1_{iqghst} + \sum_{h'} Z1'_{iqgh'st} = D1_{giqs} - SQ1_{gsiq} \qquad \forall \quad i,g,q,s,t$$

$$\sum_{m} Z2_{jqgmst} + \sum_{m'} Z1'_{jqgm'st} = D2_{gjqs} - SQ2_{gsjq} \qquad \forall \quad j,g,q,s,t$$

$$\sum_{\mathrm{r}} Z3_{kqgrst} = D3_{gkqst} - SQ3_{gskq} \qquad \forall \quad k,g,q,s,t$$

Capacity Constraints (8–13)

$$\sum_{\mathrm{g}} Z1_{iqghst} \leq CAP1_{hiq} \,.PH_{hst} \qquad \forall \quad i,q,h,s,t$$

$$\sum_{\mathrm{g}} Z1'_{iqgh'st} \leq CAP1'_{h'iq} \,.PH'_{h'st} \qquad \forall \quad i,q,h',s,t$$

$$\sum_{\mathrm{g}} Z2_{jqgmst} \leq CAP2_{mjq} \,.PM_{mst} \qquad \forall \quad j,q,m,s,t$$

$$\sum_{\mathrm{g}} Z2'_{jqgm'st} \leq CAP2_{m'jq} \,.PM'_{m'st} \qquad \forall \quad j,q,m',s,t$$

$$\sum_{\mathrm{g}} Z3_{kqgrst} \leq CAP3_{rkq} \,.PR_{rst} \qquad \forall \quad k,q,r,s,t$$

$$\sum_{\mathrm{g}} Z4_{lqgust} \leq CAP4_{ulq} \qquad \forall \quad l,q,u,s,t$$

Activation-Dependent Acceptance Constraints (14–20)

$$\sum_{i}\sum_{g}\sum_{s}\sum_{t} Z1_{iqghst} \leq X1_{hq}.M \qquad \forall \quad h,q$$
$$\sum_{i}\sum_{g}\sum_{s}\sum_{t} Z1'_{iqgh'st} \leq X1'_{h'q}.M \qquad \forall \quad h',q$$
$$\sum_{j}\sum_{g}\sum_{s}\sum_{t} Z2_{jqgmst} \leq X2_{mq}.M \qquad \forall \quad m,q$$
$$\sum_{j}\sum_{g}\sum_{s}\sum_{t} Z2'_{jqgm'st} \leq X2'_{m'q}.M \qquad \forall \quad m',q$$
$$\sum_{k}\sum_{g}\sum_{s}\sum_{t} Z3_{kqgrst} \leq X3_{rq}.M \qquad \forall \quad r,q$$
$$\sum_{l}\sum_{g}\sum_{s}\sum_{t} Z4_{lqgrst} \leq X4_{uq}.M \qquad \forall \quad u,q$$

Flow Constraints between Facilities Conditional on Activation of Both Origin and Destination Centers (21–45)

$$\sum_{m\in M} V11_{h,m,g,s,t} \leq \left(\sum_{q\in Q} Z1_{i,q,g,h,s,t}\right)\cdot \mathrm{M} \qquad \forall h\in H, i\in I, j\in J, g\in G, s\in S, t\in T$$

$$\sum_{h\in H} V11_{h,m,g,s,t} \leq \left(\sum_{q\in Q} Z2_{j,q,g,m,s,t}\right)\cdot \mathrm{M} \qquad \forall m\in M, i\in I, j\in J, g\in G, s\in S, t\in T$$

$$\sum_{m\prime\in M\prime} V12_{h,m\prime,g,s,t} \leq \left(\sum_{q\in Q} Z1_{i,q,g,h,s,t}\right)\cdot \mathrm{M} \qquad \forall h\in H, i\in I, j\in J, g\in G, s\in S, t\in T$$

$$\sum_{h\in H} V12_{h,m\prime,g,s,t} \leq \left(\sum_{q\in Q} Z2'_{j,q,g,m\prime,s,t}\right)\cdot \mathrm{M} \qquad \forall mp\in M', i\in I, j\in J, g\in G, s\in S, t\in T$$

$$\sum_{m\in M} V13_{h\prime,m,g,s,t} \leq \left(\sum_{q\in Q} Z1'_{i,q,g,h\prime,s,t}\right)\cdot \mathrm{M} \qquad \forall h'\in H', i\in I, j\in J, g\in G, s\in S, t\in T$$

$$\sum_{h\prime\in H\prime} V13_{h\prime,m,g,s,t} \leq \left(\sum_{q\in Q} Z2_{j,q,g,m,s,t}\right)\cdot \mathrm{M} \qquad \forall m\in M, i\in I, j\in J, g\in G, s\in S, t\in T$$

$$\sum_{m\prime\in M\prime} V14_{h\prime,m\prime,g,s,t} \leq \left(\sum_{q\in Q} Z1'_{i,q,g,h\prime,s,t}\right)\cdot \mathrm{M} \qquad \forall h'\in H', i\in I, j\in J, g\in G, s\in S, t\in T$$

$$\sum_{h\prime\in H\prime} V14_{h\prime,m\prime,g,s,t} \leq \left(\sum_{q\in Q} Z2'_{j,q,g,m\prime,s,t}\right)\cdot \mathrm{M} \qquad \forall m'\in M', i\in I, j\in J, g\in G, s\in S, t\in T$$

$$\sum_{r\in R} V21_{h,r,g,s,t} \leq \left(\sum_{q\in Q} Z1_{i,q,g,h,s,t}\right)\cdot \mathrm{M} \qquad \forall h\in H, i\in I, k\in K, g\in G, s\in S, t\in T$$

$$\sum_{h\in H} V21_{h,r,g,s,t} \leq \left(\sum_{q\in Q} Z3_{k,q,g,r,s,t}\right)\cdot \mathrm{M} \qquad \forall r\in R, i\in I, k\in K, g\in G, s\in S, t\in T$$

$$\sum_{r\in R} V22_{h\prime,r,g,s,t} \leq \left(\sum_{q\in Q} Z1p_{i,q,g,h\prime,s,t}\right)\cdot \mathrm{M} \qquad \forall h'\in H', i\in I, k\in K, g\in G, s\in S, t\in T$$

$$\sum_{h\prime\in H\prime} V22_{h\prime,r,g,s,t} \leq \left(\sum_{q\in Q} Z3_{k,q,g,r,s,t}\right)\cdot \mathrm{M} \qquad \forall r\in R, i\in I, k\in K, g\in G, s\in S, t\in T$$

$$\sum_{r\in R} V31_{m,r,g,s,t} \le \left(\sum_{q\in Q} Z2_{j,q,g,m,s,t}\right)\cdot \mathrm{M} \qquad \forall m\in M, j\in J, k\in K, g\in G, s\in S, t\in T$$

$$\sum_{m\in M} V31_{m,r,g,s,t} \le \left(\sum_{q\in Q} Z3_{k,q,g,r,s,t}\right)\cdot \mathrm{M} \qquad \forall r\in R, j\in J, k\in K, g\in G, s\in S, t\in T$$

$$\sum_{r\in R} V32_{m\prime,r,g,s,t} \le \left(\sum_{q\in Q} Z2'_{j,q,g,m\prime,s,t}\right)\cdot \mathrm{M} \qquad \forall m'\in M', j\in J, k\in K, g\in G, s\in S, t\in T$$

$$\sum_{m\prime\in M\prime} V32_{m\prime,r,g,s,t} \le \left(\sum_{q\in Q} Z3_{k,q,g,r,s,t}\right)\cdot \mathrm{M} \qquad \forall r\in R, j\in J, k\in K, g\in G, s\in S, t\in T$$

$$\sum_{q\in Q, i\in I} Z1_{i,q,g,h,s,t} \le \sum_{m\in M} V11_{h,m,g,s,t} + \sum_{m\prime\in M\prime} V12_{h,m\prime,g,s,t} \qquad \forall s\in S, t\in T, h\in H, g\in G$$

$$\sum_{q\in Q, i\in I} Z1'_{i,q,g,h\prime,s,t} \le \sum_{m\in M} V13_{h\prime,m,g,s,t} + \sum_{m\prime\in M\prime} V14_{h\prime,m\prime,g,s,t} \qquad \forall s\in S, t\in T, h'\in HP, g\in G$$

$$\sum_{q\in Q, j\in J} Z2_{j,q,g,m,s,t} \le \sum_{h\in H} V11_{h,m,g,s,t} + \sum_{h\prime\in H\prime} V13_{h\prime,m,g,s,t} \qquad \forall s\in S, t\in T, m\in M, g\in G$$

$$\sum_{q\in Q, j\in J} Z2'_{j,q,g,m\prime,s,t} \le \sum_{h\in H} V12_{h,m\prime,g,s,t} + \sum_{h\prime\in H\prime} V14_{h\prime,m\prime,g,s,t} \qquad \forall s\in S, t\in T, m'\in M', g\in G$$

$$\sum_{q\in Q, i\in I} Z1_{i,q,g,h,s,t} \le \sum_{r\in R} V21_{h,r,g,s,t} \qquad \forall s\in S, t\in T, h\in H, g\in G$$

$$\sum_{q\in Q, i\in I} Z1'_{i,q,g,h\prime,s,t} \le \sum_{r\in R} V22_{h\prime,r,g,s,t} \qquad \forall s\in S, t\in T, h'\in H', g\in G$$

$$\sum_{q\in Q, j\in J} Z2_{j,q,g,m,s,t} \le \sum_{r\in R} V31_{m,r,g,s,t} \qquad \forall s\in S, t\in T, m\in M, g\in G$$

$$\sum_{q\in Q, j\in J} Z2'_{j,q,g,m\prime,s,t} \le \sum_{r\in R} V32_{m\prime,r,g,s,t} \qquad \forall s\in S, t\in T, m'\in M', g\in G$$

$$\sum_{q\in Q, k\in K} Z3_{k,q,g,r,s,t} \le \sum_{h\in H} V21_{h,r,g,s,t} + \sum_{h\prime\in H\prime} V22_{h\prime,r,g,s,t} + \sum_{m\in M} V31_{m,r,g,s,t} + \sum_{m\prime\in M\prime} V32_{m\prime,r,g,s,t} \qquad \forall s\in S, t\in T, r\in R, g\in G$$

Minimum Distance (Buffer Zone) Constraints for Accommodation and Medical Facilities from Recreational Facilities (46–50)

$$(O21_{\mathrm{hr}} - CDH)\,.V21_{hrgst} \ge 0$$
$$(O22_{\prime\mathrm{r}} - CDH)\,.V22_{h'rgst} \ge 0$$
$$(O31_{\mathrm{mr}} - CDM)\,.V31_{mrgst} \ge 0$$
$$(O32_{\mathrm{m'r}} - CDM)\,.V32_{m'rgst} \ge 0$$

Service Dependency Constraints (51–53)

$$\sum_{h\in H, i\in I, q\in Q} Z1_{i,q,g,h,s,t} + \sum_{h\prime\in H\prime, i\in I, q\in Q} Z1'_{i,q,g,hp,s,t} = \sum_{i\in I, j\in J, m\in M, q\in Q} \mathrm{HM}_{i,j}\ Z2_{j,q,g,m,s,t} + \sum_{i\in I, j\in J, m\prime\in M\prime, q\in Q} \mathrm{HM}_{i,j}\ Z2'_{j,q,g,m\prime,s,t} \qquad \forall g\in G, s\in S, t\in T$$

$$\sum_{r\in R, k\in K, q\in Q} Z3_{k,q,g,r,s,t} = \sum_{i\in I, k\in K, h\in H, q\in Q} \mathrm{HR}_{i,k}\ Z1_{i,q,g,h,s,t} + \sum_{i\in I, k\in K, h\prime\in H\prime, q\in Q} \mathrm{HR}_{i,k}\ Z1'_{i,q,g,h\prime,s,t} \qquad \forall g\in G, s\in S, t\in T$$

$$\sum_{g\in G, l\in L, u\in U} Z4_{l,q,g,u,s,t} \ge \mathrm{UH}\left(\sum_{i\in I, g\in G, h\in H} Z1_{i,q,g,h,s,t} + \sum_{i\in I, g\in G, hp\in HP} Z1'_{i,q,g,h\prime,s,t}\right) + \mathrm{UM}\left(\sum_{j\in J, g\in G, m\in M} Z2_{j,q,g,m,s,t} + \sum_{j\in J, g\in G, m\prime\in M\prime} Z2'_{j,q,g,m\prime,s,t}\right) + \mathrm{UR}\sum_{k\in K, g\in G, r\in R} Z3_{k,q,g,r,s,t} \qquad \forall q\in Q, s\in S, t\in T$$

$$X1_{hq}, X1_{h'q}, X2_{mq}, X2_{m'q}, X3_{rq}, X4_{uq} \in \{0,1\} \qquad \forall\ \mathrm{h, h', m, m,' r, u, q}$$

$Z1_{iqghst}, Z'1_{iqgh'st}, Z2_{jqgmst}, Z'2_{jqgm'st}, Z3_{kqgrst}, Z4_{lqgust} \quad \geq 0, \text{integer} \quad \forall\ h, h', m, m', r, u, g, s, t, q$

$V11_{hmgst}, V12_{hm'gst}, V13_{h'mgst}, V14_{h'm'gst}, V21_{hrgst}, V22_{h'rgst}, V31_{mrgst}, V32_{m'rgst} \quad \geq 0, \text{integer} \quad \forall\ h, h', m, m', r, u, g, s, t, q$

$SQ1_{gsiq}, SQ2_{gsjq}, SQ1_{gskq} \quad \geq 0, \text{integer} \quad \forall\ h, h', m, m', r, u, g, s, t, q$

The proposed mathematical model is a Mixed-Integer Linear Programming (MILP) model based on a multi-objective optimization approach using the weighted sum method. In this model, three main objectives economic, sustainability, and efficiency are defined, while a fourth objective related to demand coverage is incorporated as a penalty term within the composite objective function. The economic objective, formulated in Equation (1), is calculated as the difference between total profit and total cost, and is normalized into a dimensionless value using normalization coefficients. Total profit includes revenues generated from accommodation, medical, recreational, and support services based on scenario probabilities and the base profit of each service. Total cost consists of fixed activation costs of facilities and operational transportation costs between centers.

The sustainability and resilience objective, presented in Equation (2), is obtained from the weighted sum of sustainability and resilience scores of activated facilities. The efficiency objective, defined in Equation (3), represents the ratio of resilient qualitative coverage based on inter-facility flows, scenario probabilities, customer group importance weights, and active capacity percentages divided by distances, which is then normalized. The fourth objective, formulated in Equation (4), represents the weighted sum of unmet demand after normalization and is included with a negative sign in the final composite objective function.

A set of constraints is defined to ensure operational feasibility and flow consistency. Demand constraints (5–7) state that the total services provided to each customer group are equal to total demand minus unmet demand. Capacity constraints (8–13) limit the outgoing flow from each facility to its maximum available capacity. Activation constraints (14–20) ensure that service acceptance at facilities is conditional on their activation; if a facility is not activated, its flow is zero, and if it is activated, at least one unit of flow is allowed.

For modeling inter-facility service flows (e.g., accommodation to medical), linearization constraints (21–45) are defined to ensure consistency between service acceptance variables (Z) and flow variables (V). Service dependency constraints (51–53) enforce proportional relationships between accommodation, medical, and recreational services based on predefined service ratios. The non-physical (non-face-to-face) support service constraint determines the volume of support services based on other service levels.

Finally, minimum distance constraints (46–50) are imposed for recreational routes (from accommodation or hospital centers to recreational facilities) with threshold values to prevent excessive proximity of high-traffic recreational centers to medical and accommodation facilities.

Results

The city of Qom, with its diverse healthcare infrastructure (such as Shahid Beheshti, Nekouei, and Valiasr hospitals), accommodation facilities (international hotels, Parsian Hotel, Mellat Hotels), and recreational attractions (the Holy Shrine, Jamkaran Mosque, and natural areas), as well as its significant inflow of tourists from neighboring countries and domestic regions, provides a suitable context for developing a healthcare tourism supply chain. The optimization results for the four objectives economic (profit), sustainability, efficiency, and demand shortage minimization indicate that focusing exclusively on any single objective leads to the weakening of other components of the system. Profit maximization activates high-return facilities such as low-cost hotels and specialized hospitals; however, it compromises sustainability and efficiency performance. In contrast, sustainability-oriented optimization prioritizes high-scoring facilities such as the Holy Shrine and Shahid Beheshti Hospital, but this leads to economic loss and unmet demand issues. The following table presents the definition of the sets based on the case study.

Table 1. Set Data for the City of Qom

Symbol	Set Type / Index No.	1	2	3	4	5	6	7
I	Types of Accommodation Services	Standard Accommodation						
J	Types of Medical Services	Cardiovascular Services (Angioplasty, Bypass Surgery)	Women's and Obstetric Services (IVF, Painless Delivery)	Dental Services (Implant, Laminate)	Cosmetic Surgery Services (Plastic Surgery, Rhinoplasty)	Ophthalmology Services (Lasik, Cataract Surgery)	Check-up and Preventive Medicine Services (Check-up)	
K	Types of Recreational & Spiritual Welfare Services	Recreational-Spiritual-Welfare						
L	Types of Support and Non-face-to-face Services	Transportation	Visa, Entry & Exit Permits, Security Inquiries	Insurance	Financial Management and Exchange Services			
G	Types of Clients (Health Tourists)	Neighboring/Gulf Countries	Other Countries	Domestic				
M	Medical Centers	Shahid Beheshti Hospital	Vali Asr Hospital	Pardisan 24-hour Clinic	Amir Al-Momenin Hospital	Nekoui Hospital	Hazrat Masoumeh Hospital	Sina 24-hour Clinic
M’	Secondary (Backup) Medical Centers	Kamkar-Arabnia Hospital	19 Dey Private Clinic	Javad Al-A’emmeh Clinic				

H	Accommodation Centers & Hotels	Qom International Hotel	Parsian Hotel Qom	Mellal Hotel Qom	Safa Hotel	Olympic Hotel	Fatima Hotel	Tashrifat Hotel Qom
H’	Secondary (Backup) Accommodation Centers & Hotels	Laleh Hotel	Khorshid Hotel	Sadeghieh Hotel Qom				
R	Recreational-Welfare Centers (Other Services)	Recreational Package 1	Recreational Package 2	Recreational Package 3	Recreational Package 4	Recreational Package 5	Recreational Package 6	Recreational Package 7
U	Service Integration, Support & Non-face Services Centers	Center 1 (Shohada St.)	Center 2 (19 Dey St.)					
T	Time Periods	Normal	High population					
S	Scenarios	Normal State (Current Situation)	Relative Supply Shortage	Relative Demand Shortage	Critical Supply Crisis	Critical Demand Crisis		
Q	Service Quality Level (Facility Level)	Excellent and Advanced	Standard and Acceptable					

At the first level, resilience and sustainability criteria are determined by experts. In this section, 19 sustainability criteria and 12 resilience criteria are considered. Then, the weight of each criterion is estimated for both primary and secondary facilities, and the score of each facility is evaluated based on these criteria. The results present the combined sustainability–resilience scores for medical and accommodation centers. These scores serve as the basis for the initial selection of candidate facilities and subsequently for selecting optimal facilities as inputs to the final optimization model.

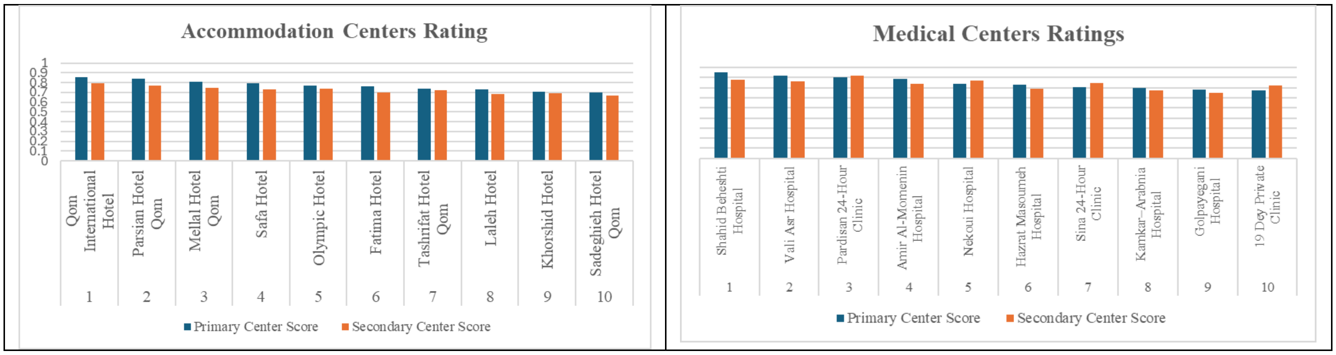

Figure 3. Scores of accommodation and healthcare centers based on the FAHP method

At the second level, a multi-objective mathematical model is defined. In this study, the normalization method is employed for weighting and aggregating the objectives. This method is commonly used in solving certain models due to its simplicity and high efficiency. In solving the model, the combined objective function incorporates weight coefficients w1 to w4 (0.35, 0.20, 0.20, and 0.25, respectively) based on expert opinions, aggregating these four components through maximization.

$$w_i = \frac{f_i - f_{min}}{f_{max} - f_{min}} \tag{54}$$

$$F_t = (w_1 . f_1) + (w_2 . f_2) + (w_3 . f_3) \; - \; (w_4 . f_4) \tag{55}$$

The results of implementing the multi-objective optimization model for Qom health tourism indicate that in the optimal scenario, all accommodation centers (7 primary and 2 secondary) and recreational centers (7 centers) are activated at both excellent and standard quality levels. This reflects the high demand for these services and the necessity of quality diversification for different customer groups (domestic, neighboring countries, and other countries). In the medical sector, the model adopts a selective approach, activating only 3 out of 7 primary centers (m1, m4, and m6), while all secondary medical centers remain inactive. This intelligent selection demonstrates that, given the fourfold objectives, the model prefers to utilize medical centers with higher sustainability scores and sufficient capacity, avoiding the activation of inefficient or secondary centers that incur high fixed costs. The integrated service centers (u1 and u2) are fully activated at both quality levels to ensure that the need for support services (transportation, visa, insurance, and finance) is covered across all scenarios. Overall, the obtained solution strikes an appropriate balance between profitability, sustainability, and demand coverage, while also approaching the economic objective by reducing fixed costs through the deactivation of unnecessary centers.

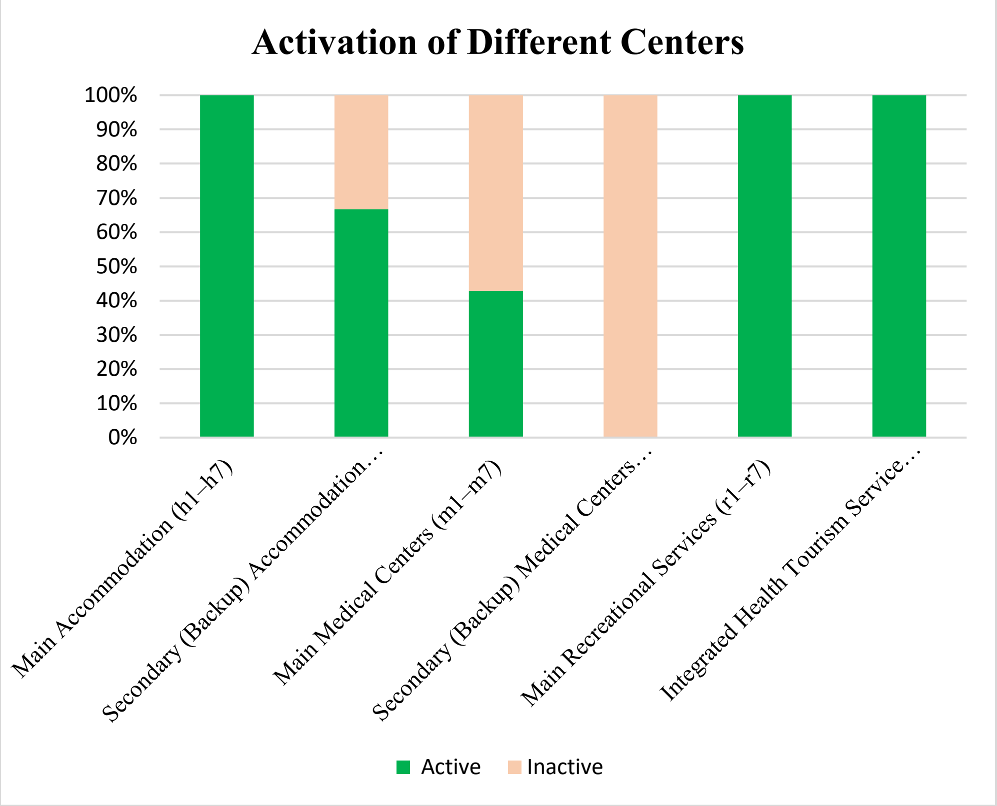

Figure 4. Activated centers in the Qom health tourism network

Analysis of the Four Objectives and Their Trade-Offs

In this study, four objective functions are defined: economic profit (f_1), average sustainability score (f_2), coverage efficiency (f_3), and minimization of unmet demand (f_4). To understand the trade-offs and alignments among these objectives, each one is optimized individually, and the values of the other functions are recorded at the optimal point. At the optimal points of f_1, the values of f_2 and f_3 are at their lowest levels, and conversely, at the optima of f_2 and f_3, f_1 becomes strongly negative. This phenomenon indicates that profitability is incompatible with sustainability and efficiency, and it is impossible to achieve high values of all three simultaneously. High sustainability at its own optimum is associated with maximum unmet demand, whereas at the optimum of f_4, sustainability is at a desirable level. This pattern suggests that selecting sustainable centers may lead to increased unmet demand due to their limited capacity. At the optimum of f_3, unmet demand is near its minimum, while at the optimum of f_4, efficiency is low. Thus, efficiency and unmet demand exhibit an inverse relationship: increasing efficiency is typically accompanied by a reduction in unmet demand, but this relationship is not linear, and achieving excellent values of both simultaneously is not possible. Although at the optimum of f_1, unmet demand is high, at the optimum of f_4, profit ranks at its second-highest level. This indicates that reducing unmet demand can lead to increased profit, and these two objectives are partially aligned. The degree of influence of the objectives varies with respect to the weight of each one. Objectives f_1 and f_3 are highly sensitive to weight changes, whereas objectives f_2 and f_4 exhibit more limited fluctuations. Figure 5 illustrates these trade-offs.

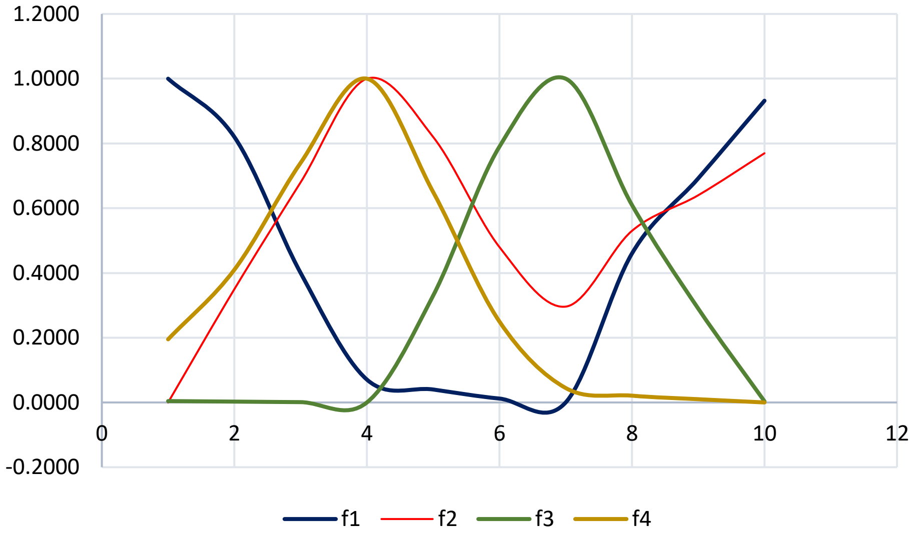

Figure 5. Conflict among the four objectives in the mathematical model

The results show that primary accommodation centers h4 and h6, along with secondary center hp2, account for the highest flow of services. Among the three active medical centers, m6 (cardiology services, excellent quality, domestic group) has the highest admission rate, followed by m4 (cosmetic services) and m1 with lower values. Furthermore, recreational center r4 (located near the Holy Shrine, excellent quality, domestic group, normal scenario) serves as the main hub for recreational services.

The support centers u1 and u2, which provide transportation, visa, insurance, and financial services, are utilized up to their maximum capacity in many scenarios. These support centers play a vital role in completing the service chain; without them, it would be impossible to meet tourist demand. The effectiveness of these centers remains high across all scenarios, and they remain partially active even in crisis conditions.

The highest overall profitability is associated with excellent-quality medical services (q1) in the normal scenario (s1) for the domestic group (g3). In subsequent scenarios (s2 and s3), profit decreases, and in crisis scenarios (s4, s5), it reaches its minimum.

The domestic group (g3) holds the largest share, accounting for approximately 70% of total flows. Neighboring countries group (g1) and other countries group (g2) constitute 20% and 10%, respectively. In terms of service quality, excellent quality (q1) has a larger share (65%) compared to standard quality (q2) with 35%, indicating a preference for higher-quality services. Regarding service type, accommodation services have the highest volume (approximately 45%), followed by support services (30%), recreational services (15%), and medical services (10%). However, in terms of economic value, medical services account for a larger share.

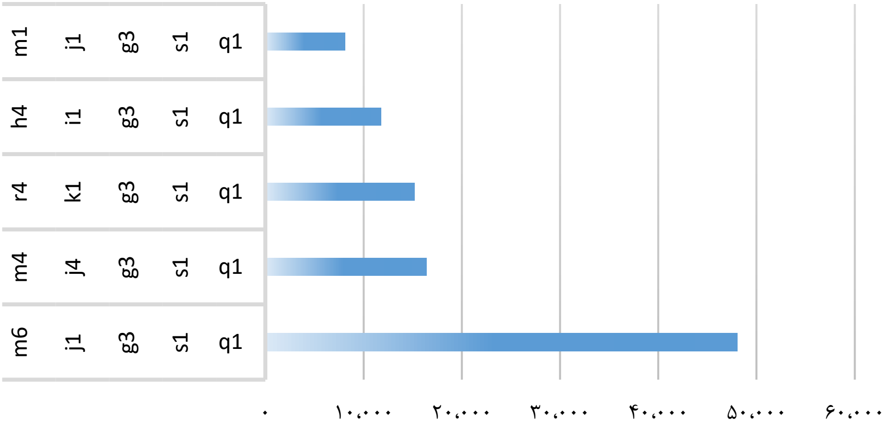

Figure 6. Centers with the highest profitability in the Qom health tourism network

In the normal scenario (s1), the highest volume of services (approximately 50% of the total) is allocated. Excellent quality dominates this scenario. In the relative supply shortage scenario (s2), the volume of services decreases, but excellent quality is still maintained. In the demand shortage scenario (s3), a further reduction is observed, and standard quality gains a higher share. In the crisis scenarios (s4 and s5), the volume of services reaches its minimum, and standard quality becomes nearly equal to excellent quality (likely due to capacity constraints).

In the normal period (t1), the volume of services is not higher than in the peak period (t2); however, in some cases such as accommodation, the peak period exhibits higher demand. Overall, the differences between periods are not significant.

The Role of Secondary (Backup) Centers and the Integrated Health Tourism Service Center (IHTSC) in Optimizing the Qom Health Tourism Model

Secondary centers hp1 and hp2 are activated at both quality levels (excellent and standard), while hp3 is activated only at the excellent level. These centers collectively cover 18% of total accommodation services. They have carried the highest flow in the normal scenario (s1), but have also remained active in crisis scenarios (s4, s5), contributing to service stability. By covering nearly one-fifth of demand, the secondary accommodation centers relieve pressure on primary centers and enhance the model's flexibility. In this study, all secondary medical centers are considered inactive. The most important reasons for not utilizing these centers are: high fixed costs relative to limited capacity, complete coverage of demand by the three active primary centers, and lower sustainability scores of these centers compared to primary ones. Therefore, secondary medical centers have made no contribution to the model, and their deactivation has been a completely optimal decision.

The results indicate that both service management centers are activated at both quality levels. These centers are utilized up to their full capacity in providing support services (transportation, visa, insurance, finance). Without these centers, it would be impossible to provide basic services for tourists (especially international ones), and the service chain would remain incomplete. Therefore, the Integrated Health Tourism Service Centers (IHTSC) constitute the support backbone of the model, and by fully leveraging their capacity, they have played a decisive role in the success of the plan.

Overall Analysis of Model Results

Objective Function Values

The final values of the objective variables indicate that the model has successfully achieved a multi-objective balance: the sustainability index (f_2) is highly favorable at 0.921, the efficiency index (f_3) stands at 0.51, and the normalized net profit is 0.421. The unmet demand penalty index (f_4) is relatively low at 0.078, resulting in a combined objective function value of 0.414. These figures demonstrate that, considering the economic weight (0.35), sustainability weight (0.20), efficiency weight (0.20), and demand coverage weight (-0.25), the model has been able to maintain high sustainability and moderate efficiency while achieving reasonable profitability and controlling unmet demand at an acceptable level.

Model Reliability and Validity

The validity of the model is ensured using real data from Qom city, including capacities, distances, costs, and scenarios based on local conditions. Numerical tests, including the examination of bounded solutions (variable values within reasonable ranges) and the absence of infeasible solutions in the output, indicate the correct performance of the model. Furthermore, the alignment of results with economic logic (e.g., greater allocation to the domestic group with higher demand) and sustainability criteria (activation of centers with higher scores such as m6 and r4) confirms the correctness of the model structure. Despite significant shortages in some scenarios, the final objective values show that the model has been able to pursue multiple objectives in a balanced manner.

Model Complexity

This model is a Mixed-Integer Linear Programming (MILP) problem with approximately 2,500 variables (including 216 binary variables for center activation and over 2,200 continuous variables for flows) and approximately 15,000 constraints. This complexity arises from the disaggregation of flows across six different dimensions (service type, quality, customer group, origin center, destination center, scenario, and period), as well as linearization equations for inter-center flows (V_{11} to V_{32}). Despite these dimensions, the solution time of 0.188 seconds indicates that the model, with its efficient structure and the use of a powerful solver (likely CPLEX or GUROBI), is well-scalable and suitable for scenario-based analyses.

Inter-Center Flow Variables (V_{11} to V_{32})

The results of the inter-center flow variables (V_{11} to V_{32}) reveal complex and purposeful patterns in the health tourism supply chain of Qom. Overall, flows are highly concentrated on a few key centers. These centers are: accommodation centers h4, h6, h1, and hp2; medical centers m4, m6, and m1; and recreational centers r4 (Holy Shrine) and r2. This concentration reflects the comparative advantages of these centers in terms of location, capacity, and sustainability scores. The secondary accommodation center hp2 plays a key role not only in accommodation flows (Z1p) but also in inter-center flows (V_{13} and V_{22}). Its flow volume to m6 and r4 rivals that of primary accommodation centers, indicating the high importance of this center in the chain. As emphasized in previous sections, there is no flow to or from secondary medical centers (mp). This result confirms the optimality of their deactivation.

The highest flows occur in the normal scenario (s1). In supply shortage (s2) and crisis scenarios (s4, s5), flows decrease and are sometimes transferred to alternative centers (such as hp1). This demonstrates the model's flexibility under different conditions. Nearly all significant flows belong to the domestic group (g3). Other groups have very small shares, which is consistent with the demand data (D_2). The very large numbers in recreational flows (V_{21}, V_{22}, V_{31}) arise from the HR_ik conversion factor (which likely represents the number of recreational visits per stay). These figures indicate the high importance of recreational services in the health tourism chain. The inter-center flows in this model depict an efficient and concentrated network. Accommodation centers h4, h6, and hp2 serve as main hubs, directing tourists to m4 and m6 hospitals and r4 and r2 recreational centers. hp2 acts as a powerful backup center and is present in all key flows. Secondary medical centers play no role in the network, and their removal is validated. The domestic group is the core of all flows, and recreational services, especially at the Holy Shrine (r4), account for a massive volume of flow. This structure demonstrates that the optimization model has successfully designed a resilient and profitable chain for Qom health tourism by focusing on a few centers with high sustainability and efficiency.

Unmet Demand Variables (SQ_1, SQ_2, SQ_3)

The results of the SQ_1, SQ_2, and SQ_3 variables show that a significant portion of accommodation, medical, and recreational service demand remains unmet across different scenarios. The highest unmet demand pertains to the domestic group (g3) in the crisis scenario (s4); for example, in the accommodation sector (SQ_1), this value for excellent quality (q1) exceeds 5,375 units. On the other hand, standard quality (q2) services generally experience lower shortages (e.g., SQ_2 for medical services j1 at 9.4 units for the domestic group in the normal scenario), indicating that the model, due to the higher profitability of standard services (according to P_2 parameters), prefers to cover this demand first and, in the event of capacity constraints, forgo providing excellent-quality services. This pattern is evident across all groups and scenarios and represents an optimal decision to maximize profit given the unmet demand penalty (f_4).

Sensitivity Analysis

Centers that play a pivotal role in inter-center flows (such as h4, h6, hp2, m4, m6, r4) are often utilized near full capacity. A one-unit increase in the capacity of these centers (e.g., CAP_1 or CAP_2) directly enables a reduction in unmet demand (SQ). Investment in increasing the capacity of high-efficiency centers yields up to a 0.225 unit improvement in the objective function per unit of shortage reduction (although the cost of capacity expansion must also be considered). A one-unit increase (million Rials) in the fixed activation costs (A_1, A_2, ...) directly increases total cost and reduces net profit. Given the economic weight of 0.35, this affects the objective function by 0.35 units. However, this effect is only meaningful for centers that are active. For inactive centers, cost changes have no effect. Therefore, policies aimed at reducing activation costs for active centers with higher priority yield the greatest returns.

An increase in demand across different groups (especially the domestic group) directly increases shortages unless excess capacity exists. Given that shortages are substantial in many cases (e.g., SQ_1 for g3.s4.i1.q1 exceeds 5,300 units), increasing demand without expanding capacity severely degrades the objective function. Conversely, reducing demand can decrease shortages and improve f_4. The current weights (0.35, 0.20, 0.20, -0.25) determine the model's orientation. Increasing the economic weight (w_1) leads to a preference for centers with higher profitability (such as m6 with cardiac services) and reduces shortages in low-profit services. Increasing the sustainability weight (w_2) may lead to the activation of centers with higher sustainability scores (such as r4 with 0.91) even at higher costs. Sensitivity analysis with respect to weights can be performed by re-solving the model with different weights, which is not feasible here. The analysis of results indicates that capacity optimization at key centers and reduction of activation costs are among the most effective strategies for improving model performance. Furthermore, altering the weights of objectives can reflect managerial priorities and yield different outcomes.

Based on the sensitivity analysis, the most effective resilience policies, in order of priority, are:

1. Adding secondary centers in high-demand sectors (e.g., accommodation) – which generate substantial profitability at relatively low cost.

2. Improving transportation infrastructure on high-traffic routes between major centers – which has a significant impact on cost reduction.
3. Increasing the capacity of existing centers, especially in medical and recreational sectors – which reduces the coverage penalty by alleviating shortages.
4. Reducing activation costs through subsidies or construction optimization.
5. Improving the percentage of active capacity under crisis conditions – by increasing center preparedness.
6. Improving sustainability scores – although this has a modest direct effect, it can help attract tourists in the long term.

Network policies such as route diversification and multiple allocation already exist in the current model, and their effectiveness can be enhanced through transportation improvements. Ultimately, a combination of these policies, tailored to budget constraints and managerial priorities, can improve the resilience of the Qom health tourism system when facing various scenarios.

Conclusion

The health tourism industry, due to its rapid growth and direct impact on the economy and employment, requires a supply chain design capable of delivering high-quality and sustainable services under both normal and crisis conditions. This paper aims to provide an integrated decision-making framework for the optimal location and allocation of support centers within this supply chain, seeking to answer key questions: How can accommodation, medical, recreational, and support centers be optimally selected and allocated? What factors influence supply chain resilience under different scenarios (normal, supply shortage, demand shortage, and crisis)? Which resilience-enhancing policies such as establishing secondary centers, increasing capacity, improving quality, etc are most effective?

The literature review reveals that existing models in this domain are predominantly single-objective and fail to simultaneously address economic, sustainability, and resilience objectives. Furthermore, the use of real data and multi-scenario analysis has received limited attention. Accordingly, the present study fills this research gap by integrating supply chain resilience concepts with multi-objective optimization, utilizing real data from Qom city including 7 primary hotels, 3 secondary hotels, 7 primary hospitals, 3 secondary clinics, 7 recreational centers, and 2 integrated service centers.

The research methodology is based on bi-level mathematical modeling and a qualitative-quantitative approach. A Mixed-Integer Linear Programming (MILP) model with approximately 2,500 variables (including 216 binary variables for center activation and over 2,200 continuous variables for flows) and 15,000 constraints has been developed. In this model, conflicting objectives including cost minimization, sustainability score maximization (considering environmental and social dimensions), and network efficiency maximization are combined using the weighted sum method with weights of 0.35, 0.20, and 0.20, along with a coverage penalty weight of -0.25. To address uncertainty, five different scenarios with varying probabilities are defined: normal (0.6), relative supply shortage (0.15), demand shortage (0.10), supply crisis (0.08), and demand crisis (0.07). Sustainability scores of centers are determined using the Fuzzy AHP method and incorporated into the model. The model is solved using GAMS software with the CPLEX/GUROBI solver, and a solution time of 0.188 seconds indicates its high efficiency.

The innovations of this research can be summarized in several key areas: First, the definition of a new health tourism network incorporating the Integrated Health Tourism Service Center (IHTSC) and inter-center flows. Second, the design of a qualitative-quantitative bi-level model under different conditions to cover various dimensions of sustainability and resilience. Third, the integration of three conflicting objectives economic, sustainability, and efficiency within a unified framework with an unmet demand penalty. Fourth, the use of real data from Qom city for validation. Fifth, sensitivity analysis of the novel IHTSC and secondary centers from a resilience perspective, providing valuable operational insights for managers.

Numerical results from model implementation show that the sustainability index (f_2) is at a highly favorable level of 0.921, attributable to the activation of centers with high sustainability scores, such as m6 hospital (score 0.76) and r4 recreational center (Holy Shrine, score 0.91). The efficiency index (f_3) is evaluated at a moderate level of 0.51, while normalized net profit reaches 0.421, indicating a successful balance among the three objectives. The coverage penalty (f_4) is relatively low at 0.078, and the combined objective function achieves a value of 0.414. Flow analysis reveals that the domestic group (g3) constitutes the largest target market with a 70% share, and centers h4, h6, hp2, m4, m6, and r4 account for the highest service flows. Interestingly, the secondary accommodation center hp2, with a flow of 228 units (excellent quality), plays a key role in feeding m6 hospital and r4 recreational center, effectively competing with primary centers. On the other hand, all secondary medical centers (mp) remain inactive, confirming the optimality of their deactivation due to high costs and sufficient capacity of primary centers.

Shortage values indicate that the highest unmet demand pertains to the domestic group in the crisis scenario (s4); for example, in the excellent-quality accommodation sector, this value exceeds 5,375 units. Notably, standard quality (q2) exhibits lower shortages than excellent quality (q1) across all sectors, indicating that the model, due to the higher profitability of standard services (according to P parameters), prefers to cover this demand first. The multi-objective optimization model has successfully allocated services such that centers with high sustainability (e.g., m6, r4, u1) achieve the highest utilization. The domestic group, as the primary target market, receives the largest share of services, with excellent quality prioritized. Support services are utilized up to full capacity, demonstrating their importance in the chain. In terms of profitability, excellent-quality medical services in the normal scenario generate the highest value. Across different scenarios, the model exhibits appropriate flexibility, shifting allocation toward standard quality as demand decreases. These results can serve as a decision-making basis for investment and infrastructure development in Qom's health tourism sector. From a managerial and operational perspective, sensitivity analysis identifies the following priorities for investment and system improvement:

First, adding secondary centers in high-demand sectors such as accommodation given the return of 1,106 units in the objective function for a center similar to hp2 is the optimal option. Second, improving transportation infrastructure on high-traffic routes such as h1→m4 and h6→r4, as each minute reduction in travel time improves the objective function by up to 2.68 units. Third, increasing capacity of existing key centers such as h4, m6, and r4, with a return of 0.225 per unit of capacity increase, is far more effective than activating a new center. Fourth, quality management given the lower shortage of standard services suggests that incentive policies for utilizing higher quality (q2) through cost reduction or profit enhancement can increase profitability. Fifth, increasing the percentage of active capacity (PH, PM, and PR) under crisis scenarios through greater preparedness and storage yields up to 0.5 units of improvement in the objective function. Additionally, route diversification and multiple allocation, already present in the current model, have enhanced system flexibility.

Finally, future research is suggested to extend in the following directions: extending the model to a dynamic framework incorporating seasonal and periodic variations in demand and capacity; employing metaheuristic methods such as genetic algorithms or particle swarm optimization to solve larger-scale problems; analyzing uncertainty using advanced fuzzy approaches or additional stochastic scenarios; integrating social criteria such as job creation, tourist satisfaction, and cultural impacts as new objectives; designing public-private partnership mechanisms for infrastructure financing; and validating the model in other tourist-friendly cities in Iran, such as Mashhad, Shiraz, and Isfahan, to enable generalizability of the results. This framework can serve as a powerful tool for managers and decision-makers in the health tourism industry to design a resilient, cost-effective, and environmentally sustainable network.

Author Contributions

For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used “Conceptualization, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, X.X.; writing—review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript."

Conceptualization, A.S. and M.R.F.; methodology, A.S., M.R.F. and A.K.; software, A.S.; validation, M.R.F., A.K. and C.D.K.; formal analysis, A.S. and A.K.; investigation, A.S., M.R.F., A.K. and C.D.K.; resources, M.R.F. and C.D.K.; data curation, A.S. and A.K.; writing original draft preparation, A.S.; writing review and editing, M.R.F., A.K. and C.D.K.; visualization, A.S. and A.K.; supervision, M.R.F. and C.D.K.; project administration, M.R.F.; funding acquisition, M.R.F. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

Data available on request from the authors.

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Conflict of interest

The authors declare no conflict of interest.

References

Ahmadimanesh, F. & Paydar, M. M. & Asadi-Gangraj, E. (2019). Designing a mathematical model for dental tourism supply chain. *Tourism Management*. 75. 404-417. 10.1016/j.tourman.2019.06.001. https://doi.org/10.1016/j.tourman.2019.06.001

Ahmadimanesh, F., Pourmehdi, M., & Paydar, M. M. (2021). Evaluation and prioritisation of potential locations for investment in dental tourism. *Soft computing*, *25*(24), 15313-15333. https://doi.org/10.21203/rs.3.rs-211614/v1

Asadi, R. (2011). Strategies for Development of Iran Health Tourism. European Journal of Social Sciences. 23. 329-344. https://www.researchgate.net/publication/215897808_Strategies_for_Development_of_Iran_Health_Tourism

Babaei, Y. S., Sazvar, Z., Nayeri, S., & Tavakkoli-Moghaddam, R. (2024). A two-stage framework for a resilient medical tourism supply chain considering social aspects and supplier evaluation under uncertainty: A real-case study. *Annals of operations research*, 1-47. https://doi.org/10.1007/s10479-024-06128-9?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

Bagheri, M., Mobasheri, A. A., Shekari, F., Moaven, Z. & Nikbakht, A. (2023). Identifying and prioritizing strategies for Iran's medical tourism development. *Interdisciplinary Journal of Management Studies*, *17*(1), 331-345. doi: 10.22059/ijms.2023.340379.675010. https://doi.org/10.22059/ijms.2023.340379.675010

Bayev, V. V., Bayeva, O. V., Bakhov, I. S., Antonenko, I. Y., & Melnyk, I. L. (2020). Digital marketing as an innovative communication tool in the health tourism system. *International Journal of Engineering Trends and Technology*, *68*(8), 36-40. https://doi.org/10.14445/22315381/IJETT-V68I8P207S

Butler, R. W., & Szromek, A. R. (2019). Incorporating the value proposition for society with business models of health tourism enterprises. *Sustainability*, *11*(23), 6711. https://doi.org/10.3390/su11236711

Büyüközkan, G., Mukul, E., & Kongar, E. (2021). Health tourism strategy selection via SWOT analysis and integrated hesitant fuzzy linguistic AHP-MABAC approach. *Socio-economic planning sciences*, *74*, 100929. https://doi.org/10.1016/j.seps.2020.100929

Campón-Cerro, A. M., Di-Clemente, E., Hernández-Mogollón, J. M., & Folgado-Fernández, J. A. (2020). Healthy water-based tourism experiences: Their contribution to quality of life, satisfaction and loyalty. *International journal of environmental research and public health*, *17*(6), 1961. https://doi.org/10.3390/ijerph17061961?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

Charati, M. K., Gholian-Jouybari, F., Hajiaghaei-Keshteli, M., Paydar, M. M., & Sadeghi, F. (2024). Designing a sustainable dental tourism supply chain considering waste treatment. *Annals of operations research*, *342*(1), 173-214. https://doi.org/10.1007/s10479-023-05779-4?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

de la Hoz-Correa, A. (2017). Past themes and future trends in medical tourism research: A co-word analysis. Tourism Management. 65. 10.1016/j.tourman.2017.10.001. https://doi.org/10.1016/j.tourman.2017.10.001

Ding, L. (2024). Tourist choice of sustainable hot springs tourism under post-COVID-19 pandemic period: a case in Colorado. *International Journal of Tourism Research*, *26*(1), e2619. https://doi.org/10.1002/jtr.2619

Dinkoksung, S., Pitakaso, R., Khonjun, S., Srichok, T., & Nanthasamroeng, N. (2023). Modeling the medical and wellness tourism supply chain for enhanced profitability: An open innovation approach. *Journal of Open Innovation: Technology, Market, and Complexity*, *9*(3), 100137. https://doi.org/10.1016/j.joitmc.2023.100137

Etemadi, M., & Kasraei, A. (2020). Supply Chain Management (Vol. 1). Tehran: Sharif University of Technology Press.

Garjan, H. S., Paydar, M. M., & Divsalar, A. (2023). A sustainable supply chain for a wellness tourism center considering discount and quality of service. *Expert Systems with Applications*, *211*, 118682. https://doi.org/10.1016/j.eswa.2022.118682

Ge, H. B., & Chen, X. L. (2024). Research on tourist satisfaction and behavioral intention in ecological health tourism activities in bama, guangxi based on structural equation model. *GeoJournal of Tourism and Geosites*, *52*(1), 221-230. https://doi.org/10.30892/gtg.52121-1198

Global Spa Summit (2011). *Medical Tourism and Wellness: The New Wave of Health Tourism*. New York: Global Spa Summit. https://globalwellnessinstitute.org/wp-content/uploads/2018/06/Wellness-Tourism-and-Medical-Tourism-Report-Final.pdf

Godlewska, A., Mazurek-Kusiak, A., & Soroka, A. (2023). Push and pull factors influencing the choice of a health resort by Polish treatment-seekers. *BMC Public Health*, *23*(1), 2192. https://doi.org/10.1186/s12889-023-17086-5

Gössling, S., Hall, C. M., & Weaver, D. B. (2009). Sustainable tourism futures: Perspectives on systems, restructuring and innovations. In *Sustainable tourism futures* (pp. 1-16). Routledge. https://doi.org/10.4324/9780203884256.ch1

Govindan, K., Fattahi, M., & Keyvanshokooh, E. (2017). Supply chain network design under uncertainty: A comprehensive review and future research directions. European journal of operational research, 263(1), 108-141, 108-141. https://doi.org/10.1016/j.ejor.2017.04.009. https://doi.org/10.1016/j.ejor.2017.04.009

Hall, C. (2011). Health and medical tourism: Kill or cure for global public health?. Tourism Review. 66. 4-15. 10.1108/16605371111127198. https://doi.org/10.1108/16605371111127198

Hamzehpour, H., Ashktorab, T., & Esmaeili, M. (2023). Safe acceptance in the nurses' cultural care of medical tourists in Iran: a qualitative study. *BMC Health Services Research*, *23*(1), 399. https://doi.org/10.1186/s12913-023-09378-8?urlappend=%3Futm_source%3Dresearchgate.net%26utm_medium%3Darticle

Hendijani, A., Zarei, A., & Karimi, T. (2020). Identification and analysis of factors affecting uncertainty in the supply chain. Industrial Management Perspective, 10(39), 9-34.

Hosseini, S. M., Paydar, M. M., Alizadeh, M., & Triki, C. (2021). Ecotourism supply chain during the COVID-19 pandemic: A real case study. *Applied soft computing*, *113*, 107919. https://doi.org/10.1016/j.asoc.2021.107919

Ivanov, D. (2021). *Introduction to supply chain resilience: Management, modelling, technology*. Springer Nature. https://doi.org/10.1007/978-3-030-70490-2

Ivanov, D., & Dolgui, A. (2020). Viability of intertwined supply networks: extending the supply chain resilience angles towards survivability. A position paper motivated by COVID-19 outbreak. *International journal of production research*, *58*(10), 2904-2915. https://doi.org/10.1080/00207543.2020.1750727

Iwu, C. G., Choto, P., & Tengeh, R. K. (2019). Sustainability issues of health tourism Non-Profit-Organisations. African Journal of Hospitality Tourism and Leisure. 8. 1-15. https://www.ajhtl.com/uploads/7/1/6/3/7163688/article_80_vol_8_5__2019_cput.pdf

Jiang, L., Wu, H., & Song, Y. (2022). Diversified demand for health tourism matters: From a perspective of the intra-industry trade. *Social Science & Medicine*, *293*, 114630. https://doi.org/10.1016/j.socscimed.2021.114630

Kaewkitipong, L., Chen, C., & Ractham, P. (2021). Examining factors influencing COVID-19 vaccine tourism for international tourists. *Sustainability*, *13*(22), 12867. https://doi.org/10.3390/su132212867

Kazakov, A., Mosiiuk, S., Voitovych, S., Sorokoumov, H., & Saichuk, V. (2023). Logistics management of health resorts and tourism facilities. DOI: https://doi.org/10.55365/1923.x2023.21.63

Khalili, S. M., Pooya, A., Kazemi, M., & Fakoor Saghih, A. M. (2022). Designing a sustainable and resilient gasoline supply chain network under uncertainty (case study: gasoline supply chain network of

Khorasan Razavi province). *Industrial Management Journal*, *14*(1), 27-79. https://doi.org/10.22059/imj.2022.334524.1007896

Khani, F., Rezaei, M., & Mohammadi, S. (2011). Analysis of the concept of tourism from a sociological perspective. Journal of Social Sciences, 18(53), 125-156.

Lee, C. W., & Li, C. (2019). The process of constructing a health tourism destination index. *International journal of environmental research and public health*, *16*(22), 4579. https://doi.org/10.3390/ijerph16224579

Liao, C., Lin, Y., Li, Z., & Zhan, X. (2023). Exploring the relationship between different types of reference group influence and young consumers' health tourism intention. *Social Sciences & Humanities Open*, *8*(1), 100649. https://doi.org/10.1016/j.ssaho.2023.100649

Lin, C. H. (2014). Effects of cuisine experience, psychological well-being, and self-health perception on the revisit intention of hot springs tourists. *Journal of Hospitality & Tourism Research*, *38*(2), 243-265. https://doi.org/10.1177/1096348012451460

Mazroui Nasrabadi,E . (2022). Presenting a Model of the Critical Success Factors of the Health Tourism Supply Chain: a Fuzzy Cognitive Map Approach. *Health Information Management*, *19*(2), 79-87. doi: 10.48305/him.2023.41125.1050

Mazroui, N. E., & Mohammadipour, E. A conceptual model of critical success factors in improving the resilience of the health tourism supply chain: A case study. (2022). Journal of Health Administration, 25(2), 9–25. https://www.academia.edu/95888202/A_conceptual_model_of_critical_success_factors_in_improving_the_resilience_of_the_health_tourism_supply_chain_A_case_study

Mazroui-Nasrabadi,E and Mohammadipour,E . (2021). Representing a Model of Health Tourism Supply Chain Risks, Meta-Synthesis Approach, and Structural-Interpretive Modeling. *Health Information Management*, *18*(4), 172-181. doi: 10.22122/him.v18i4.4342

Mihăilă, D., Bistricean, P. I., Gaceu, R. O., Emandi, E. M., Mihăilă, E. V., & Horodnic, V. D. (2024). A bioclimatic evaluation of sustainable tourist activities in western Romania. *Heliyon*, *10*(8). https://doi.org/10.1016/j.heliyon.2024.e29510

Mojaradi, Z., Bozorgi-Amiri, A., & Hashemzadeh, S. (2021). Strategic planning for supply chain of health tourism in Iran: Razavi hospital. *Razavi Journal of Medicine*, *9*(2), 21-33. doi:10.30483/rijm.2021.254150.1005

Nikraftar, T., Hosseini, E., & Moghaddam, A. (2017). Identify factors affecting medical tourism attraction in Iran. 20. 64-74. https://www.researchgate.net/publication/336265625_Identify_factors_affecting_medical_tourism_attraction_in_Iran

Paç, B. (2023). A Biobjective Approach to Assigning Recreational Activities to Medical Tourists. *International Journal of Computational and Experimental Science and Engineering*, *9*(3), 296-306. https://www.ijcesen.com/index.php/ijcesen/article/view/270

Perkumienė, M., & Šuminas, A. (2019). *Cooperation perspectives in sustainable medical tourism: The case of Lithuania. Sustainability, 11 (13), 3584*. https://doi.org/10.3390/su11133584

Pu, B., Du, F., Zhang, L., & Qiu, Y. (2021). Subjective knowledge and health consciousness influences on health tourism intention after the COVID-19 pandemic: A prospective study. *Journal of Psychology in Africa*, *31*(2), 131-139. https://doi.org/10.1080/14330237.2021.1903181

Rahman, A., Wisnoentoro, R., & Narjoko, D. A. (2024). *The impact of tourism development on CO₂ emissions: Evidence from ASEAN economies* [Thesis, Universitas Islam Internasional Indonesia]. UIII Repository. https://repository.uiii.ac.id/items/31a47f42-d471-4869-976d-a0b8019af011

Ridderstaat, J. (2023). Measuring hidden demand and price behavior from US outbound health tourism spending. *Tourism Economics*, *29*(3), 759-787. DOI: 10.1177/13548166211067925

Sabouhi, F., Pishvaee, M. S., & Jabalameli, M. S. (2018). Resilient supply chain design under operational and disruption risks considering quantity discount: A case study of pharmaceutical supply chain. *Computers & industrial engineering*, *126*, 657-672. https://doi.org/10.1016/j.cie.2018.10.001

Salehi-Esfahani, S., Ridderstaat, J., & Ozturk, A. B. (2021). Health tourism in a developed country with a dominant tourism market: the case of the United States' travellers to Canada. *Current Issues in Tourism*, *24*(4), 536-553. DOI: 10.1080/13683500.2020.1724081

Shalbafian, A. (2015). Health Tourism: Concepts, Markets, and Development Strategies. Tehran: Mahkameh Publications.

Smith, M. (2015). Baltic health tourism: Uniqueness and commonalities. *Scandinavian Journal of Hospitality and Tourism*, *15*(4), 357-379. https://doi.org/10.1080/15022250.2015.1024819

Smith, M., & Puczkó, L. (2015). More than a special interest: Defining and determining the demand for health tourism. *Tourism recreation research*, *40*(2), 205-219. https://doi.org/10.1080/02508281.2015.1045364

Tafti, H. F., Esteghlal, A., al-Modaresi, S. A., Beheshtipour, Z., & Mirhosseini, S. M. (2023). Investigation and Evaluation of the Most Important Factors Affecting Non-Native Medical Tourists' Reception of the Historical City of Yazd Using Delphi Technique. *Quarterly Journal of Management Strategies in Health System*. http://dx.doi.org/10.18502/mshsj.v8i2.13652

Tavana, M., Yazdani, M., & Di Caprio, D. (2017). An application of an integrated ANP–QFD framework for sustainable supplier selection. *International Journal of Logistics Research and Applications*, *20*(3), 254-275. https://doi.org/10.1080/13675567.2016.1219702

Tokpanov, Y., Atasoy, E., Mendybayev, E., Abdimanapov, B., Andasbayev, Y., Mukhitdinova, R., & Inkarova, Z. (2021). Prospects for the development of health tourism on lake Ray in the Almaty region of the Republic of Kazakhstan. *Geo Journal of Tourism and Geosites*, *37*(3), 888-893. https://doi.org/10.30892/gtg.37320-722

Torkzadeh, L., Jalilian, H., Rahmani, H., Bakhshi, M., Hashemzadeh, S., Faryabi, M., & Khodayari-Zarnaq, R. (2024). Value-based market segmentation of West Asian medical tourism market: A case of Iran. *Iranian Journal of Public Health*, *53*(4), 924. doi: 10.18502/ijph.v53i4.15570. PMID: 39444475; PMCID: PMC11493577.

Torkzadeh, L., Jalilian, H., Zolfagharian, M., Torkzadeh, H., Bakhshi, M., & Khodayari-Zarnaq, R. (2024). Market segmentation in the health tourism industry: A systematic review of approach and criteria. *Journal of Policy Research in Tourism, Leisure and Events*, *16*(1), 69-88. https://doi.org/10.1080/19407963.2021.1988622

Tsekouropoulos, G., Vasileiou, A., Hoxha, G., Dimitriadis, A., & Zervas, I. (2024). Sustainable approaches to medical tourism: Strategies for Central Macedonia/Greece. *Sustainability*, *16*(1), 121. https://doi.org/10.3390/su16010121

UNWTO. (2019). *UNWTO Tourism Definitions. Madrid*: World Tourism Organization. DOI: https://doi.org/10.18111/9789284420858

Yan, X., & He, S. (2020). The co-evolution of therapeutic landscape and health tourism in bama longevity villages, China: An actor-network perspective. *Health & Place*, *66*, 102448. https://doi.org/10.1016/j.healthplace.2020.102448

Zavari Z, Mazroui Nasrabadi E, Sadeqi Arani Z. (2022). Presentation of a Collaboration Model in Medical Tourism Supply Chain. *Iran Journal of Culture and Health Promotion*, 6 (2) :360-364. http://dx.doi.org/10.22034/6.2.21

Zhang, Q., Zhang, H., & Xu, H. (2021). Health tourism destinations as therapeutic landscapes: Understanding the health perceptions of senior seasonal migrants. *Social Science & Medicine*, *279*, 113951. https://doi.org/10.1016/j.socscimed.2021.113951