OPTIMAL SITE SELECTION OF A PANDEMIC HOSPITAL USING MULTI-CRITERIA DECISION-MAKING APPROACH

Gökhan Ağaç
Department of Health Management,
Sakarya University of Applied Sciences,
Sakarya, Turkey
gokhanagac@subu.edu.tr

İsmail Şimşir
ismailsimsir@subu.edu.tr

ABSTRACT

The COVID-19 pandemic has spread rapidly and affected the whole world. During the process of combating the pandemic, it has become apparent that some physical infrastructures such as intensive care units have been insufficient to meet the current demand. The aim of this study is to select the optimal location for a pandemic hospital and determine the critical factors affecting the selection. The Analytical Hierarchy Process approach is implemented in the study with 27 criteria used to evaluate the alternatives. The data of the study are collected from 23 experts. The result of the analysis proposes the optimal location to establish a pandemic hospital. In addition, the three most important criteria that affect the location selection of the pandemic hospital are Risk, Accessibility, and Opportunities and threats, respectively. Moreover, the results of the sensitivity analysis show that the outputs of the proposed model are robust. A location selection problem for a pandemic hospital was addressed and the factors affecting the location selection are discussed in this study. The proposed model is expected to be a guide for health policymakers, healthcare managers, and public and private investment decision-makers as a decision support system.

Keywords: pandemic hospital; location selection; covid-19; Analytical Hierarchy Process; multi-criteria decision-making

1. Introduction

Human beings have faced with many kinds of disasters whether man-made or natural throughout history including earthquakes, tsunamis, volcanic eruptions, landslides, nuclear disasters and epidemics. These types of disasters affect limited areas; however, pandemics affect wide geographic areas. In addition to being a disaster, the novel COVID-19 outbreak, which was declared a pandemic by the WHO on March 11, 2020 (WHO, 2020a), can be characterized as the biggest multifaceted crisis ever faced by the modern world resulting in more than 263 million cases and 5.2 million deaths as of December 6, 2021 (WHO, 2020b).

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The novel COVID-19 pandemic has created an "overwhelming burden" on most of the world's health systems. Governments across the world have pulled out all the stops to ameliorate that overwhelming burden, but have experienced challenges due to the deficiency of available physical resources, especially ICU's (Intensive Care Units). Therefore, beyond allocation of resources, increased ICU and monitorized (semi-ICU) bed capacity and decreased contamination risk are of utmost importance when it comes to building a pandemic hospital.

Hospitals should also be kept safe and functional considering emergency and disaster conditions. Therefore, just like with other disaster conditions, the proper selection of the location of a pandemic hospital would have a direct effect on the survival and/or rapid recovery of an affected population; having a building with sufficient capacity in pandemic conditions will have the same effect. The location and capacity would also have a direct effect on cost and other benefits for its post-pandemic usage.

On the other hand, decisions regarding the selection of a hospital location could depend on personal accounts instead of objective analyses (Soltani & Marandi, 2011). However, an improper decision without conducting an analytical process would increase investment and operational costs and affect the lives of the affected population in the pandemic management cycle. Such a decision might also stymie future usage in the post-pandemic era.

An appropriate decision made after an analytical process regarding hospital site selection would however have positive repercussions on different parties such as optimizing the allocation of medical resources by matching the provision of health care with the social and economic demands, coordinating the urban and rural health service development, and easing social contradictions on the aspect of government; and access to health care by reducing the time of rescue, satisfying people's medical needs as well as enhancing the quality of life of the citizens; and cost savings for investors and operators of the hospital (Sen, 2017).

A decision-making process regarding facility location involves identification, analysis, assessment and selection of a number of alternatives. After recognition of a need for additional capacity, a decision is made about the "best" possible location (Yang & Lee, 1997). In such a process, determining the criteria that should be considered and their possible level of impact on site selection is of primary importance. In other words, the selection of the location of urban facilities is a strategic issue due to the several side effects and multiple conflicting criteria involved in such a decision (Oppio et al., 2016). Therefore, appropriate site selection for a hospital is an important determinant in the success or failure of the facility (Senvar et al., 2016).

Different multi-criteria decision-making (MCDM) tools have been applied in health care. The Analytical Hierarchy Process (AHP) is a MCDM tool that decomposes a complex multi-criteria decision problem into a hierarchy (Saaty, 1980). Based on a review of the existing literature regarding hospital site selection, there is scant research utilizing AHP or its extended forms in this field. Yap et al. (2019) performed a systematic review of multi-criteria decision-making methods for location selection applications. They reported that the Analytic Hierarchy Process was the most used approach for location selection problems. In addition, Gul and Guneri (2021) conducted a literature review on the selection of a hospital location. They also found that the AHP is the most preferred MCDM method. As such, there are a number of studies in the literature using the AHP to find the best hospital location. Some of them use the AHP separately (Chatterjee & Mukherjee, 2013; Chiu & Tsai, 2013; Jalaliyoon et al., 2015; Wu et al., 2007) and others combine it with various approaches (Al-Shabeeb et al., 2016; Şen & Demiral, 2016; Triantono & Susetyarto, 2017; Vahidnia et al., 2009). There are only a few studies on the location selection of a pandemic hospital (Alkan & Kahraman, 2021; Aydin & Seker, 2021; Boyacı & Şişman, 2021; Zolfani et al., 2020). The present study contributes to eliminating this deficiency in the relevant literature.

The originality of the present paper primarily comes from its application of the AHP to problem of location selection for a pandemic hospital. Second, pandemic conditions are considered when defining criteria, sub-criteria and alternatives. Third, 27 criteria were included (8 main and 19 sub-criteria) which adds richness to existing knowledge on a subject that has limited research. Lastly, the opinions of top actors in relevant provinces who are of utmost importance when considering building a pandemic hospital were solicited. These actors include urban and regional planners in a metropolitan municipality, engineers in the health facilities department of the provincial health directorate, top managers of hospitals, academics from Medicine Faculty and Attending Physicians (especially from the departments of Infectious Diseases and Clinical Microbiology and Diseases of the Chest), academics from nursing and health management departments of universities in the same province, and finally top managers of the provincial health directorate. This study also provides policy makers with a tool to use in their decision-making process to choose a hospital location in both current and possible future pandemic cases.

The remainder of this study is organized as follows. Section 2 explains the Analytical Hierarchy Process methodology. Section 3 presents an implementation of the proposed approach for solving the location problem of a pandemic hospital. Section 4 discusses the results of the research and finally, conclusions are discussed in the last section.

2. Analytical Hierarchy Process methodology

The Analytical Hierarchy Process is one of the multi-criteria decision-making techniques that is capable of solving large, dynamic, and complex real-world problems (Yang & Lee, 1997). The AHP was first proposed by Thomas L. Saaty in the 1970s as a quantitative decision-making approach that converts qualitative judgments into numerical values (Soltani & Marandi, 2011). There are three basic principles for the implementation of the AHP as follows: (i) identifying the problem and building a hierarchy, (ii) forming a comparative decision-making preference matrix, and (iii) determining factor weights (Colak et al., 2020). Therefore, the outputs of the implementation provide support to the decision-maker, who is facing a complex problem, during the decision phase.

Let A be $n \times n$ matrix, $w = (w_1, w_2, w_3, \dots, w_n)$ a weight vector of matrix A. Then, the AHP approach steps can be explained as follows (Bhushan & Rai, 2004; Saaty, 1984, 1990):

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Step 1: The problem is decomposed into a hierarchy including goal, criteria, sub-criteria, and alternatives. The first, second, third, and last level of the hierarchy represent the goal, criteria, sub-criteria, and alternatives, respectively.

Step 2: The pairwise comparison matrices are established. First, the relative importance for the particular element is collected from experts or decision-makers according to the hierarchy of the problem using the fundamental scale (Table 1). Then, collected data are imported into a pairwise comparison matrix. A pairwise comparison matrix $A_{n\times n} = \left(w_i/w_j\right)$ $(i, j = 1, 2, 3, \dots, n)$ is composed as follows:

$$A = \begin{array}{cccccc} C_i & A_1 & A_2 & A_3 & \cdots & A_n \\ A_1 & w_1/w_1 & w_1/w_2 & w_1/w_3 & \cdots & w_1/w_n \\ A_2 & w_2/w_1 & w_2/w_2 & w_2/w_3 & \cdots & w_2/w_n \\ A_3 & w_3/w_1 & w_3/w_2 & w_3/w_3 & \cdots & w_3/w_n \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ A_n & w_n/w_1 & w_n/w_2 & w_n/w_3 & \cdots & w_n/w_n \end{array}$$

where C_i $(i = 1, 2, 3, \dots, n)$ and A_i $(i = 1, 2, 3, \dots, n)$ represent criteria and element/alternative, respectively. Let $a_{ij} = w_i/w_j$. Then, $a_{ij} = 1/a_{ji}$ and $a_{ii} = 1$ $(i, j = 1, 2, 3, \dots, n)$. Thus, the pairwise comparison matrix transforms into the matrix $A_{n\times n} = (a_{ij})$ as follows:

$$A = \begin{array}{cccccc} C_i & A_1 & A_2 & A_3 & \cdots & A_n \\ A_1 & a_{11} & a_{12} & a_{13} & \cdots & a_{1n} \\ A_2 & a_{21} & a_{22} & a_{32} & \cdots & a_{2n} \\ A_3 & a_{31} & a_{32} & a_{33} & \cdots & a_{3n} \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ A_n & a_{n1} & a_{n2} & a_{n3} & \cdots & a_{nn} \end{array}$$

Table 1
Fundamental scale

Importance	Explanation (between A_i and A_j alternatives)
1	A_i and A_j have equal importance
3	A_i is moderately more important than A_j
5	A_i is strongly more important than A_j
7	A_i is very strongly more important than A_j
9	A_i is extremely more important than A_j
2,4,6,8	Intermediate values

Step 3: The relative weights of the pairwise comparison matrix are calculated. To determine the relative weights, each of the column entries of the matrix are first normalized by dividing by their column sum, and then each row is averaged.

Step 4: The consistency of the pairwise comparison matrix is evaluated. Let λ_{max} be the maximum eigenvalue of the comparison matrix. Then, the consistency of matrix A is calculated using the following equation:

$$CR = CI/RI,$$

where CI (consistency index) $= (\lambda_{max} - n)/(n-1)$, RI (random index) is given in Table 2, and $Aw = \lambda_{max}w$. In addition, the consistency ratio (CR) should be less than 0.1 (Saaty, 1980).

Table 2
Random Index (RI)

n	2	3	4	5	6	7	8
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41

Step 5: Global weights (also known as synthesis value) are calculated. Local weights become global weights by multiplying them by the weight of the corresponding criterion/alternative and then adding over all scores with respect to which the comparison is made.

3. Implementation of case study

This section consists of four-phases. In the first phase, the study identified the alternatives, and the main and sub-criteria related to optimal location selection for a pandemic hospital. In the second phase, it decomposed the problem into a hierarchy including goal, criteria, sub-criteria, and alternatives. In the next phase, the pairwise comparison matrices were established by collecting data from experts and used to obtain their local weights, consistency, and global weights. In the last phase, a sensitivity analysis was performed to observe the robustness of the proposed model.

3.1 Identification of alternatives, criteria, and sub-criteria

3.1.1 Study area

Sakarya is a province located in northwestern Turkey. The province's total area is 4,824 square kilometers (GDM, 2021) and population at the end of 2019 was 1,029,650 (TURKSTAT, 2021). The province is located in the midst of Turkey's crowded provinces and has 16 districts. There are three central districts among these districts. As a result of face-to-face interviews with the managers of health institutions in the province, the central districts were specified as potential locations for a pandemic hospital. These districts are Adapazarı, Erenler, and Serdivan. The location of these provinces on a map is shown in Figure 1. The area, population, and density information about the provinces obtained from the Turkey Statistical Institute (TURKSTAT, 2021) and General Directorate of Mapping (GDM, 2021) are presented in Table 3. According to this data, whereas Adapazarı is first in terms of size and population with 324 square kilometers area and a population of 276,385, Serdivan has the highest population density (1,135 per square kilometer). Adapazarı, Erenler, and Serdivan have elderly populations of 9.34%, 8.31%, and 6.54%, respectively. In addition, the number of the population with a university level education is 37,733, 10,396, and 28,601, respectively.

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Table 3
Statistical information for potential locations at the end of 2019

Alternatives	Area (square kilometres)	Current population	Population density	Elderly population (≥65 years)	Population with a university education
Adapazarı	324	276,385	853	25,826	37,733
Erenler	136	89,128	655	7,407	10,396
Serdivan	130	147,500	1,135	9,650	28,601

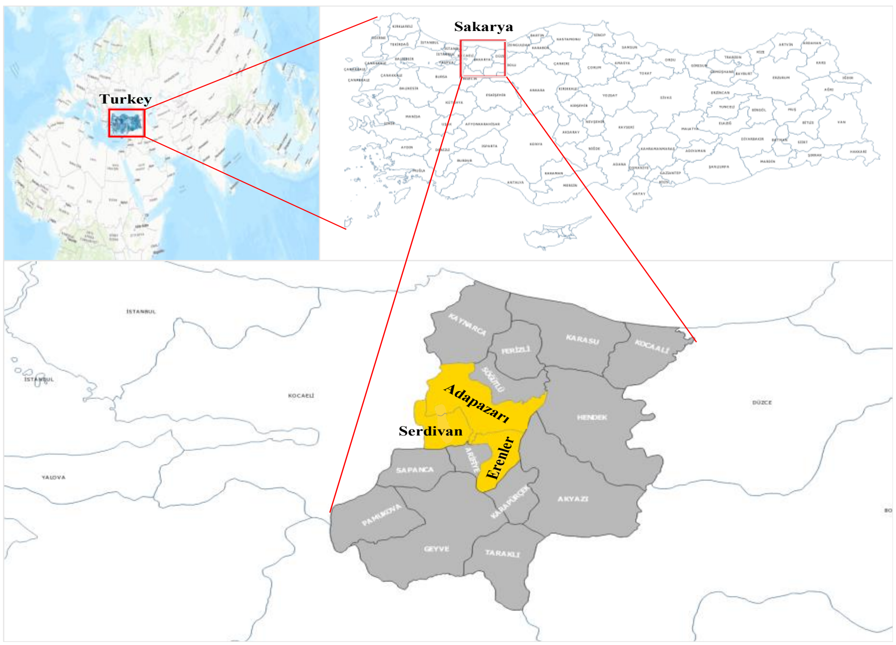

Figure 1 Map of the study area

3.1.2 Main and sub-criteria

In this section, the main and sub-criteria that affect the selection of the optimal location for a pandemic hospital are determined. First, a literature review related to hospital location selection was performed. Then, as a result of the literature review, eight main criteria and nineteen sub-criteria were determined (Table 4). Later, two infectious disease experts were asked for their views on the appropriateness of the specified criteria. They confirmed that the specified criteria are suitable for the selection of a pandemic hospital location, and stated that they would not add or remove any criteria. In addition, they stated that meeting the environmental risk criteria would have a positive effect on patient's health.

Table 4
Criteria and sub-criteria to determine optimal location selection for a pandemic hospital

		Reference						
Criteria	Sub-criteria	**Wu et al. (2007)**	**Vahidnia et al. (2009)**	**Soltani and Marandi (2011)**	**Kumar et al. (2016)**	**Senvar et al. (2016)**	**Adalı and Tuş (2019)**	**Zolfani et al. (2020)**
Cost	Investment cost	√			√	√		√
	Labor cost	√				√		
	Land cost	√	√	√	√	√		
Demographics	Current population	√			√	√	√	
	Population density	√	√	√		√		
	Age profile	√				√		
	Education profile				√			
Accessibility	Travel time		√					
	Transfer modes				√	√	√	√
Risk	Disaster risk						√	
	Environmental risk				√		√	√
Parcel characteristics	Ground conditions			√				
	Capacity expansion					√	√	√
	Park area					√	√	
Government	Incentives	√					√	√
Opportunities and threats	Market conditions	√				√	√	√
	Economic conditions	√						
Human resources	Availability of skilled staffs				√	√		
	Availability of other staffs				√	√		

3.2 Hierarchical representation of the problem

The problem is decomposed into a four-level hierarchical structure (Figure 2). Level 1 includes the problem goal that is the optimal location selection for a pandemic hospital. Level 2 represents the main criteria of the problem that are *Cost, Demographics, Accessibility, Risk, Parcel characteristics, Government, Opportunities and threats,* and *Human resources*. Below the main criteria, nineteen sub-criteria are determined as the next level. The lowest level of the hierarchy, level 4, shows the alternatives for the problem.

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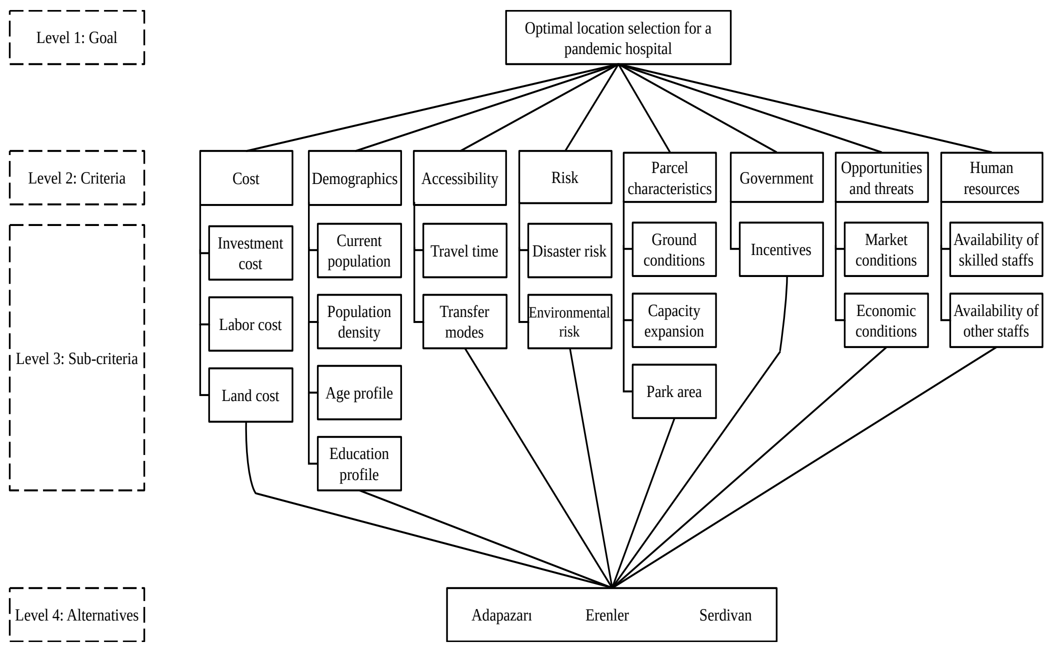

Figure 2 Decomposition of the problem into a hierarchy

3.3 Analysis of data

3.3.1 Collection of data

The data of the study were collected between December 2, 2020 and January 7, 2021 from a total of 23 people who have expertise in their field. In addition, the titles of the experts who are in the positions of health manager, administrative manager, and healthcare academician are presented in Table 5. The study also uses secondary data that are available and accessible for the alternatives according to the sub-criteria of *Demographics*. The secondary data were obtained from the Turkey Statistical Institute (TURKSTAT, 2021) and General Directorate of Mapping (GDM, 2021). However, considering the up-to-dateness of the data, the rate of data to be used in the calculation is determined as 70% for data collected from experts and 30% for secondary data.

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Table 5
Distribution of the expert titles

Title of expert position	Number of people
Health directorate, financial services specialist	3
Health directorate, public health facilities planner	3
Health directorate, support services manager	1
Hospital, administrative financial manager	1
Hospital, chest diseases specialist	1
Hospital, health services manager	1
Hospital, technical services manager	1
Municipality, city and regional planner	6
Municipality, city planning branch manager	1
Municipality, development and urban planning department, geophysical engineer	1
University, healthcare management, academician	2
University, infectious diseases specialist, academician	2
Total	23

The consistency of each comparison matrix collected from the experts is tested. Some pairwise comparison matrices have consistency ratios greater than 10%. These comparison matrices need to be re-evaluated by the expert making the comparison. After this improvement process, when the consistency ratio values are examined, the main criteria vary between 0.0673 and 0.0993, the sub-criteria vary between 0.000 and 0.0941, and the alternatives vary between 0.000 and 0.0960.

3.3.2 Findings from the pairwise comparison matrices

In this section, the aggregate pairwise comparison matrices, relative weights, and ranking for criteria, sub-criteria, and alternatives are given. The aggregate pairwise comparison matrices are obtained from the aggregated values which are calculated using the geometric mean. The findings are presented in Table 6 for criteria, Tables 7-13 for sub-criteria, and Tables 14-21 for alternatives. In addition, the global weights and ranking of the elements in these three levels are shown in Tables 21-22.

According to Table 6, the relative weights of criteria with regard to *Goal* are *Cost* (0.110), *Demographics* (0.059), *Accessibility* (0.201), *Risk* (0.206), *Parcel characteristics* (0.073), *Government* (0.075), *Opportunities and threats* (0.193), and *Human resources* (0.0839).

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Table 6
Aggregate pairwise comparison matrix, weights, and consistency values for criteria

Goal	Cost	Demographics	Accessibility	Risk	Parcel characteristics	Government	Opportunities and threats	Human resources	Weights
Cost	1.000	2.433	0.431	0.399	1.434	2.038	0.519	1.405	0.110
Demographics	0.411	1.000	0.242	0.315	1.009	0.978	0.242	0.761	0.059
Accessibility	2.318	4.128	1.000	1.133	2.560	2.614	0.787	2.091	0.201
Risk	2.508	3.173	0.882	1.000	2.686	2.521	0.944	3.244	0.206
Parcel characteristics	0.698	0.991	0.391	0.372	1.000	0.985	0.483	0.731	0.073
Government	0.491	1.022	0.383	0.397	1.015	1.000	0.556	0.919	0.075
Opportunities and threats	1.925	4.128	1.271	1.060	2.068	1.798	1.000	2.015	0.193
Human resources	0.712	1.314	0.478	0.308	1.369	1.088	0.496	1.000	0.083
$\lambda_{max} = 8.1263902; CI = 0.0180557; RI = 1.41; CR = 0.0128055 \leq 0.1$									

Considering the findings from the sub-criteria, the relative weights for the three sub-criteria of *Cost* criteria are *Investment cost* (0.640), *Labor cost* (0.181), and *Land cost* (0.180). For the four sub-criteria of the *Demographics* criterion, the relative weights are *Current population* (0.199), *Population density* (0.355), *Age profile* (0.340), and *Education profile* (0.107). The relative weights of the *Travel time* and *Transfer modes* sub-criteria according to the *Accessibility* criterion are 0.553 and 0.447, respectively. For the *Risk* criterion, the relative weights of sub-criteria are *Disaster risk* (0.682) and *Environmental risk* (0.318). According to the *Parcel characteristics* criterion, the relative weights for *Ground conditions* is 0.535, for *Capacity expansion* is 0.236, and *Park area* is 0.229. The relative weights for the two sub-criteria of the *Opportunities and threats* criterion are *Market conditions* (0.339) and *Economic conditions* (0.661). Lastly, the relative weights of *Availability of skilled staff* and *Availability of other staff* according to the *Human resources* criterion are 0.867 and 0.133, respectively.

Table 7
Aggregate pairwise comparison matrix, weights, and consistency values for the sub-criteria of cost

Cost	Investment cost	Labor cost	Land cost	Weights
Investment cost	1.000	3.487	3.617	0.640
Labor cost	0.287	1.000	0.992	0.181
Land cost	0.276	1.008	1.000	0.180
$\lambda_{max} = 3.0002210; CI = 0.0001105; RI = 0.58; CR = 0.0001906 \leq 0.1$				

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Table 8
Aggregate pairwise comparison matrix, weights, and consistency values for the sub-criteria of demographics

Demographics	Current population	Population density	Age profile	Education profile	Weights
Current population	1.000	0.596	0.486	2.086	0.199
Population density	1.679	1.000	1.120	3.338	0.355
Age profile	2.056	0.893	1.000	2.830	0.340
Education profile	0.479	0.300	0.353	1.000	0.107
$\lambda_{max} = 4.0174169; CI = 0.0058056; RI = 0.90; CR = 0.0064507 \leq 0.1$					

Table 9
Aggregate pairwise comparison matrix and weights for the sub-criteria of accessibility

Accessibility	Travel time	Transfer modes	Weights
Travel time	1.000	1.239	0.553
Transfer modes	0.807	1.000	0.447

Table 10
Aggregate pairwise comparison matrix and weights for the sub-criteria of risk

Risk	Disaster risk	Environmental risk	Weights
Disaster risk	1.000	2.143	0.682
Environmental risk	0.467	1.000	0.318

Table 11
Aggregate pairwise comparison matrix, weights, and consistency values for the sub-criteria of parcel characteristics

Parcel characteristics	Ground conditions	Capacity expansion	Park area	Weights
Ground conditions	1.000	3.321	2.361	0.535
Capacity expansion	0.301	1.000	2.012	0.236
Park area	0.424	0.497	1.000	0.229
$\lambda_{max} = 3.0000365; CI = 0.0000182; RI = 0.58; CR = 0.0000315 \leq 0.1$				

Table 12
Aggregate pairwise comparison matrix and weights for the sub-criteria of opportunities and threats

Opportunities and threats	Market conditions	Economic conditions	Weights
Market conditions	1.000	0.512	0.339
Economic conditions	1.951	1.000	0.661

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Table 13
Aggregate pairwise comparison matrix and weights for the sub-criteria of human resources

Human resources	Availability of skilled staff	Availability of other staff	Weights
Availability of skilled staff	1.000	6.535	0.867
Availability of other staff	0.153	1.000	0.133

According to Tables 14-21, the alternative which ranks first with regard to *Investment cost*, *Labor cost*, and *Land cost* is *Erenler* with relative weights of 0.437, 0.362, and 0.483, respectively. Considering the sub-criteria of *Demographics*, the alternatives that rank first are *Adapazarı* (0.428) for *Current population*, *Serdivan* (0442) for *Population density, Adapazarı* (0.471) for *Age profile,* and *Serdivan* (0.449) for *Education profile. Erenler* (0.433) for *Travel time* and *Serdivan* (0.352) for *Transfer modes* between the sub-criteria of *Accessibility* are more dominate than the other alternatives. The safest alternatives with respect to *Disaster risk* and *Environmental risk* are *Erenler* (0.359) and *Adapazarı* (0.399). The optimal alternatives with regard to *Parcel characteristics* are *Adapazarı* (0.422) for *Ground conditions*, *Erenler* (0.509) for *Capacity expansion*, and *Erenler* (0.415) for *Park area*. According to the *Incentives* sub-criteria, the most advantageous alternative is *Erenler* with a relative weight of 0.489. *Erenler* is the most attractive alternative in terms of both *Market conditions* and *Economic conditions* with relative weights of 0.392 and 0.454 respectively. Lastly, the highest access to *Human resources* in terms of *Availability of skilled staff* and *Availability of other staff* is *Erenler* with relative weights of 0.357 and 0.453, respectively.

Table 14
Aggregate pairwise comparison matrix, weights, and consistency values of the sub-criteria of cost for alternatives

Investment cost	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.694	1.092	0.297
Erenler	1.441	1.000	1.671	0.437
Serdivan	0.916	0.598	1.000	0.266
$\lambda_{max} = 3.0003983; CI = 0.0001991; RI = 0.58; CR = 0.0003433 \leq 0.1$				
Labor cost	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.978	1.340	0.362
Erenler	1.022	1.000	1.289	0.362
Serdivan	0.746	0.776	1.000	0.276
$\lambda_{max} = 3.0004192; CI = 0.0002096; RI = 0.58; CR = 0.0003614 \leq 0.1$				
Land cost	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.721	2.055	0.348
Erenler	1.386	1.000	2.852	0.483
Serdivan	0.487	0.351	1.000	0.169
$\lambda_{max} = 3.0000002; CI = 0.0000001; RI = 0.58; CR = 0.0000002 \leq 0.1$				

Table 15
Aggregate pairwise comparison matrix, weights, and consistency values of the sub-criteria of demographics for alternatives

Current population	Adapazarı	Erenler	Serdivan	Weights of comparison matrix (70%)	Weights of numerical data (30%)	Aggregate weight (100%)
Adapazarı	1.000	1.682	0.966	0.381	0.539	0.428
Erenler	0.594	1.000	0.590	0.229	0.174	0.212
Serdivan	1.035	1.694	1.000	0.391	0.288	0.360
$\lambda_{max} = 3.0000836; CI = 0.0000418; RI = 0.58; CR = 0.0000721 \leq 0.1$						
Population density	Adapazarı	Erenler	Serdivan	Weights of comparison matrix (70%)	Weights of numerical data (30%)	Aggregate weight (100%)
Adapazarı	1.000	1.645	0.729	0.339	0.323	0.334
Erenler	0.608	1.000	0.495	0.214	0.248	0.224
Serdivan	1.372	2.019	1.000	0.448	0.429	0.442
$\lambda_{max} = 3.0013926; CI = 0.0006963; RI = 0.58; CR = 0.0012005 \leq 0.1$						
Age profile	Adapazarı	Erenler	Serdivan	Weights of comparison matrix (70%)	Weights of numerical data (30%)	Aggregate weight (100%)
Adapazarı	1.000	1.462	1.370	0.414	0.602	0.471
Erenler	0.684	1.000	1.042	0.294	0.173	0.257
Serdivan	0.730	0.959	1.000	0.292	0.225	0.272
$\lambda_{max} = 3.0012637; CI = 0.0006318; RI = 0.58; CR = 0.0010894 \leq 0.1$						
Education profile	Adapazarı	Erenler	Serdivan	Weights of comparison matrix (70%)	Weights of numerical data (30%)	Aggregate weight (100%)
Adapazarı	1.000	1.817	0.627	0.326	0.492	0.375
Erenler	0.550	1.000	0.432	0.193	0.135	0.176
Serdivan	1.595	2.314	1.000	0.481	0.373	0.449
$\lambda_{max} = 3.0056356; CI = 0.0028178; RI = 0.58; CR = 0.0048583 \leq 0.1$						

Table 16
Aggregate pairwise comparison matrix, weights, and consistency values of the sub-criteria of accessibility for alternatives

Travel time	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.476	0.622	0.213
Erenler	2.101	1.000	1.180	0.433
Serdivan	1.608	0.848	1.000	0.354
$\lambda_{max} = 3.0011626$; $CI = 0.0005813$; $RI = 0.58$; $CR = 0.0010023 \leq 0.1$				
Transfer modes	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	1.148	1.020	0.350
Erenler	0.871	1.000	0.823	0.297
Serdivan	0.981	1.215	1.000	0.352
$\lambda_{max} = 3.0006487$; $CI = 0.0003243$; $RI = 0.58$; $CR = 0.0005592 \leq 0.1$				

Table 17
Aggregate pairwise comparison matrix, weights, and consistency values of the sub-criteria of risk for alternatives

Disaster risk	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.937	1.222	0.347
Erenler	1.067	1.000	1.184	0.359
Serdivan	0.819	0.844	1.000	0.294
$\lambda_{max} = 3.0010319$; $CI = 0.0005160$; $RI = 0.58$; $CR = 0.0008896 \leq 0.1$				
Environmental risk	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	1.548	1.148	0.399
Erenler	0.646	1.000	0.861	0.271
Serdivan	0.871	1.161	1.000	0.331
$\lambda_{max} = 3.0024901$; $CI = 0.0012450$; $RI = 0.58$; $CR = 0.0021466 \leq 0.1$				

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Table 18
Aggregate pairwise comparison matrix, weights, and consistency values of the sub-criteria of parcel characteristics for alternatives

Ground conditions	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	1.434	1.487	0.422
Erenler	0.698	1.000	1.042	0.295
Serdivan	0.673	0.959	1.000	0.283
$\lambda_{max} = 3.0000027; CI = 0.0000014; RI = 0.58; CR = 0.0000024 \leq 0.1$				
Capacity expansion	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.590	1.680	0.306
Erenler	1.695	1.000	2.711	0.509
Serdivan	0.595	0.369	1.000	0.185
$\lambda_{max} = 3.0002702; CI = 0.0001351; RI = 0.58; CR = 0.0002329 \leq 0.1$				
Park area	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.906	1.934	0.383
Erenler	1.104	1.000	2.019	0.415
Serdivan	0.517	0.495	1.000	0.202
$\lambda_{max} = 3.0003421; CI = 0.0001710; RI = 0.58; CR = 0.0002949 \leq 0.1$				

Table 19
Aggregate pairwise comparison matrix, weights, and consistency values of the sub-criteria of government for alternatives

Incentives	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.514	1.137	0.265
Erenler	1.944	1.000	1.892	0.489
Serdivan	0.879	0.529	1.000	0.246
$\lambda_{max} = 3.0027120; CI = 0.0013560; RI = 0.58; CR = 0.0023379 \leq 0.1$				

Table 20
Aggregate pairwise comparison matrix, weights, and consistency values of the sub-criteria of opportunities and threats for alternatives

Market conditions	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.699	0.908	0.284
Erenler	1.430	1.000	1.166	0.392
Serdivan	1.101	0.858	1.000	0.324
$\lambda_{max} = 3.0013008; CI = 0.0006504; RI = 0.58; CR = 0.0011213 \leq 0.1$				
Economic conditions	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.623	1.228	0.295
Erenler	1.606	1.000	1.732	0.454
Serdivan	0.815	0.577	1.000	0.251
$\lambda_{max} = 3.0018702; CI = 0.0009351; RI = 0.58; CR = 0.0016122 \leq 0.1$				

Table 21
Aggregate pairwise comparison matrix, weights, and consistency values of the sub-criteria of human resources for alternatives

Availability of skilled staffs	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.818	0.835	0.292
Erenler	1.223	1.000	1.021	0.357
Serdivan	1.198	0.980	1.000	0.350
$\lambda_{max} = 3.0000000; CI = 0.0000000; RI = 0.58; CR = 0.0000000 \leq 0.1$				
Availability of other staffs	Adapazarı	Erenler	Serdivan	Weights
Adapazarı	1.000	0.663	1.277	0.305
Erenler	1.509	1.000	1.843	0.453
Serdivan	0.783	0.543	1.000	0.242
$\lambda_{max} = 3.0002177; CI = 0.0001088; RI = 0.58; CR = 0.0001876 \leq 0.1$				

Considering Table 22, *Risk* is the most important criterion in the selection of a pandemic hospital location. Following this, *Accessibility* and *Opportunities and threats* are ranked second and third, respectively, with a slight difference. The *Cost* factor also ranks fourth among the other factors. The remaining factors are *Human resources*, *Government*, *Parcel characteristics*, and *Demographics*, respectively. Considering global weights and rankings for the sub-criteria, *Disaster risk* (0.140), which is one of the *Risk* factors, is the most important sub-criterion for evaluation of the optimal selection problem. The sub-criterion that ranks second is *Economic conditions* (0.128). The *Travel time* sub-criterion is ranked third with a global weight of 0.111. The rank order of the remaining sub-criteria with regard to their global weights are *Transfer modes* (0.090), *Incentives* (0.075), *Availability of skilled staff* (0.072), *Investment cost* (0.070), *Environmental risk* (0.066), *Market conditions* (0.065), *Ground conditions* (0.039), *Population density* (0.021), *Age profile* (0.020), *Labor cost* (0.020), *Land cost* (0.020), *Capacity expansion* (0.017), *Park area* (0.017), *Current population* (0.012), *Availability of other staff* (0.011), and *Education profile* (0.006), respectively.

Table 22
Global weights and rankings

Level 2: Main criteria			Level 3: Sub-criteria				
Criteria	Weights	Ranking	Sub-criteria	Local weights	Local ranking	Global weights	Global ranking
Cost	0.110	4	Investment cost	0.640	1	0.070	7
			Labor cost	0.181	2	0.020	13
			Land cost	0.180	3	0.020	14
Demographics	0.059	8	Current population	0.199	3	0.012	17
			Population density	0.355	1	0.021	11
			Age profile	0.340	2	0.020	12
			Education profile	0.107	4	0.006	19
Accessibility	0.201	2	Travel time	0.553	1	0.111	3
			Transfer modes	0.447	2	0.090	4
Risk	0.206	1	Disaster risk	0.682	1	0.140	1
			Environmental risk	0.318	2	0.066	8
Parcel characteristics	0.073	7	Ground conditions	0.535	1	0.039	10
			Capacity expansion	0.236	2	0.017	15
			Park area	0.229	3	0.017	16
Government	0.075	6	Incentives	1.000	1	0.075	5
Opportunities and threats	0.193	3	Market conditions	0.339	2	0.065	9
			Economic conditions	0.661	1	0.128	2
Human resources	0.083	5	Availability of skilled staff	0.867	1	0.072	6
			Availability of other staff	0.133	2	0.011	18

According to Table 23, the synthesis values that are the final relative weights of the alternatives are *Adapazarı* (0.317), *Erenler* (0.382), and *Serdivan* (0.300). The optimal location selection for a pandemic hospital with regard to the synthesis values of the alternatives is *Erenler*. The rank order of the other remaining alternatives is *Adapazarı* and *Serdivan*, respectively.

Table 23
Synthesis value and ranking for alternatives

Level 4: Alternatives				
	Weights			
Sub-criteria	Global	Adapazarı	Erenler	Serdivan
Investment cost	0.070	0.297	0.437	0.266
Labor cost	0.020	0.362	0.362	0.276
Land cost	0.020	0.348	0.483	0.169
Current population	0.012	0.428	0.212	0.360
Population density	0.021	0.334	0.224	0.442
Age profile	0.020	0.471	0.257	0.272
Education profile	0.006	0.375	0.176	0.449
Travel time	0.111	0.213	0.433	0.354
Transfer modes	0.090	0.350	0.297	0.352
Disaster risk	0.140	0.347	0.359	0.294
Environmental risk	0.066	0.399	0.271	0.331
Ground conditions	0.039	0.422	0.295	0.283
Capacity expansion	0.017	0.306	0.509	0.185
Park area	0.017	0.383	0.415	0.202
Incentives	0.075	0.265	0.489	0.246
Market conditions	0.065	0.284	0.392	0.324
Economic conditions	0.128	0.295	0.454	0.251
Availability of skilled staff	0.072	0.292	0.357	0.350
Availability of other staff	0.011	0.305	0.453	0.242
Synthesis value		0.317	0.382	0.300
Ranking		2	1	3

3.4 Sensitivity analysis

A sensitivity analysis is a useful approach to measure the response of the model under changing environmental conditions. In this study, a sensitivity analysis was performed for alternatives according to the main criteria using SuperDecisions (version 2.10) software. The analysis results are shown in Figure 3. In the graph, *Adapazarı*, *Erenler*, and *Serdivan* are presented with red, blue, and black lines, respectively. In addition, relative weights corresponding to the intersection points of the lines are given in parentheses. According to the figure, the *Erenler* region, which ranked first for the establishment of a pandemic hospital, does not change its ranking despite the changes in the relative weights of most criteria. However, the ranking order changes for the following three criteria: *Demographics*, *Risk*, and *Parcel characteristics*. Considering the three criteria, when the relative weight of *Demographics* reaches 0.293, the *Erenler* region is replaced by the *Adapazarı* region. If the relative weight of the *Risk* criterion exceeds 0.731, *Adapazarı* ranks first among the alternatives. Lastly, when the relative weight of *Parcel characteristics* is equal to or more than 0.850, *Adapazarı* becomes the most optimal location to establish a pandemic hospital instead of *Erenler*. Taking into account the current relative weights of the criteria, the *Demographics*, *Risk*, and *Parcel characteristics* criteria must be increased by at least 497%, 355%, and 1164%, respectively, for these changes to occur. Also, sensitivity performance is observed after

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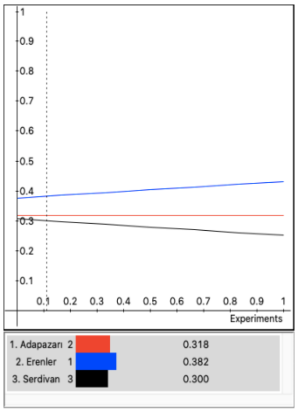
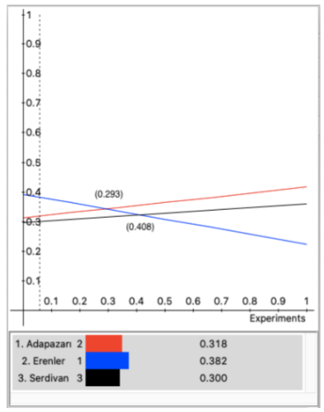
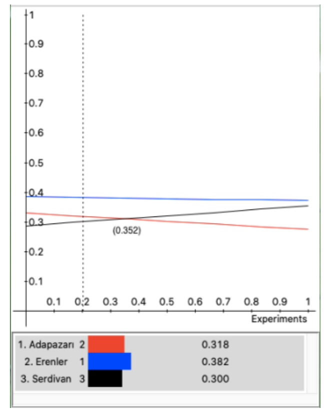
the relative weights of each main criterion are changed by 50% (Figure 4). However, despite this increase, there is no change in the rank order of all alternatives according to their relative weights. Therefore, the outputs of the decision-making model are robust.



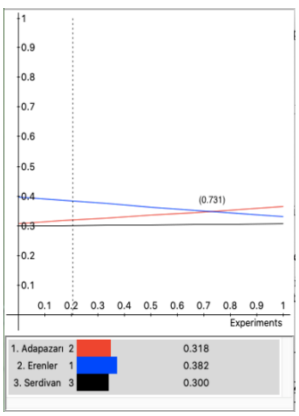
(a) Sensitivity analysis for Cost



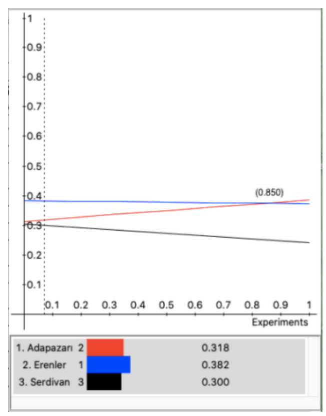
(b) Sensitivity analysis for Demographics



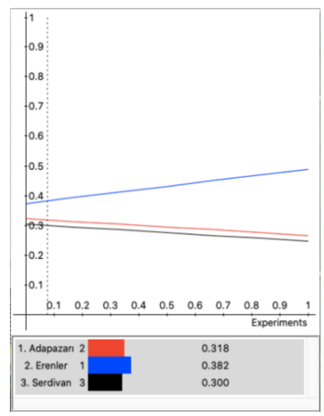
(c) Sensitivity analysis for Accessibility



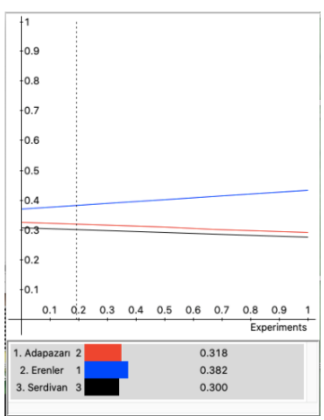
(d) Sensitivity analysis for Risk



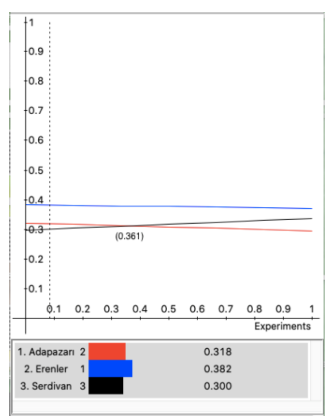
(e) Sensitivity analysis for Parcel characteristics



(f) Sensitivity analysis for Government

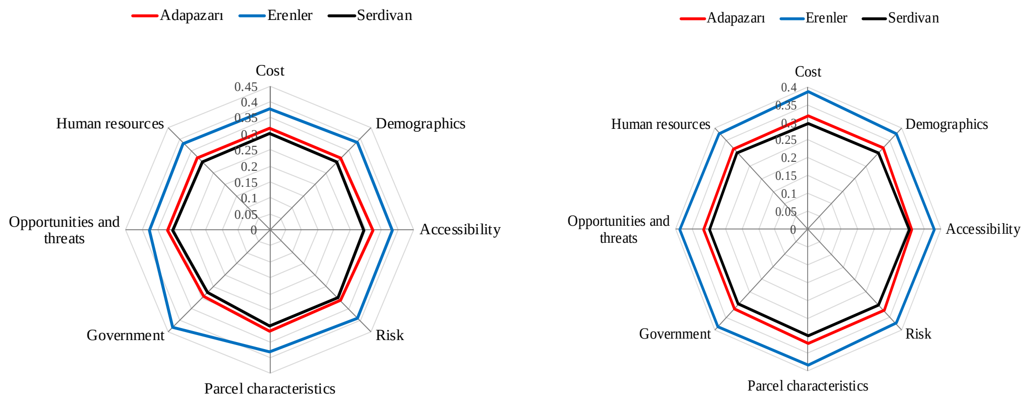


(g) Sensitivity analysis for Opportunities and threats



(h) Sensitivity analysis for Human resources

Figure 3 Sensitivity analysis of alternatives according to main criteria



(a) All main criteria are decreased by 50% (b) All main criteria are increased by 50%

Figure 4 Sensitivity analysis of alternatives when all main criteria are changed by 50%

4. Discussion

The COVID-19 pandemic has infected more than a hundred million people all over the world, and approximately two million people have died (CSSE, 2021). Many countries were not prepared for such a large-scale pandemic, particularly concerning the physical resources of hospitals. This unpreparedness was witnessed in the insufficiency of ICU's for patients with severe conditions and the difficulty of prevention of contact with other patients and the risk of contamination. In order to overcome this challenge, there is a need for pandemic hospitals that can provide a suitable environment for infected patients. The problem of location selection for a pandemic hospital is a critical decision because it is strategic. This study focuses on determining the optimal location selection for a pandemic hospital. The proposed model is a useful tool that will provide decision support to health managers and decision-makers in evaluating location alternatives.

The results of the study show that the most effective criterion in the selection of a pandemic hospital is the *Risk* factor. Risk is very important in terms of hospital establishment. If the risk of disaster is high, the costs required to eliminate the risk will increase. In addition, risks such as air, water, noise, and even traffic will adversely affect patients receiving services from the hospital. *Disaster risk*, which is a sub-criterion of the risk criterion, has become the most important among all the sub-criteria. This may be due to the increase in cost, as well as the fact that Sakarya Province is located on a fault line and is in the first-degree earthquake zone (AFAD, 2021). On the other hand, the *Environmental risk* sub-criterion ranks eighth. When the criteria were determined, the experts were asked for their opinions about the criteria, and they stated that the *Environmental risk* factor is very important for a pandemic hospital. However, the *Environmental risk* sub-criteria ranked in the middle of the criteria. This is an interesting result, which could be because the experts think that the *Environmental risk* factor does not have a very negative impact on the region. This idea is supported by a study conducted by the Ministry of Environment and Urbanization on the air pollution rate,

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where it was determined that the air quality index value for Sakarya Province was good (AQI, 2021). This and similar evidence may explain the situation.

The second interesting finding is that the *Opportunities and threats* criterion ranks third which is above the *Cost* criterion. In addition, whereas *Economic conditions* ranked second among the sub-criteria, the *Market conditions* criterion ranked in the middle. In fact, this situation should be analyzed from two perspectives. Will the pandemic hospital be built by the public or the private sector? The situation can be explained according to the answer given to the question. The *Opportunities and threats* may rank at the top if the hospitals are built by the private sector because the private sector wants to see a return on its investment in the medium or long-term. The situation depends on the correct analysis of the opportunities and threats of the region. It is expected that the sub-criteria of this criterion will also rank at the top; however, it is observed that *Market conditions* does not meet this requirement. This may be because there are no pandemic hospitals that can compete in the region and the opening of a second pandemic hospital is not foreseen in the near future. If the plan is for the hospital to be built by the public sector, *Opportunities and threats* cannot be expected to rank first. However, whereas the *Opportunities and threats* refer directly to the market, a pandemic hospital established by the public sector is not built to gain profit. The pandemic hospital is already established for an extraordinary situation and has no intention of producing a market opportunity. Since the priority is to control the pandemic, a pandemic hospital can be opened via the public sector even if it has negative market or economic conditions.

Another interesting finding is that the *Demographics* criterion and sub-criteria ranked last. The demographic structure of the region where a hospital will be established under normal conditions is an important factor. For example, the high population will increase the number of potential patients. However, the experts stated that the demographic characteristics of the region are not important when it comes to the pandemic hospital. The underlying reason may be that there is no pandemic hospital in Sakarya and neighboring provinces and the infected patients have no alternative.

Lastly, the criteria rankings obtained from the study were compared for both a general hospital and a pandemic hospital. First, when looking at the studies addressing the location selection problem for general hospitals, in studies conducted in Taiwan and China, respectively (Wu et al., 2007; Lin & Tsai, 2010), the *Government* criterion was ranked first; however, it ranked last in the current study. In a similar study conducted in Turkey (Şahin et al., 2019), the *Government* criterion ranked last as in the current study. This situation can be explained by the fact that the incentives that are given for the location selection of a pandemic hospital in Turkey are not sufficient. The *Demographics* criterion, which is also called the *demand criterion*, took the first two places in different studies (Kumar et al., 2016; Lin & Tsai, 2010; Wu et al., 2007). However, the criterion ranks last in the current study. This situation may be caused by the special situation of the pandemic hospital in which the pandemic hospital is not open to every region like general hospitals. Therefore, the patient's visit to the hospital is considered independent of the demographics dimension. Patients can even be transferred to this region from neighboring regions because it will be the only available pandemic hospital in the region. Considering Zolfani et al. (2020)'s study on a pandemic hospital, the first criterion in the study was "distance from industrial areas". In the current study, this criterion, which

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corresponds to the *Environmental risk* factor, ranked in the middle. It should come as no surprise that the criterion ranked first because their study was carried out in Istanbul which is Turkey's most populous city and has advanced industrialization. In addition, whereas the *Land cost* criterion ranked third in their study, it is in the last place in the current study. This situation can be explained by the fact that the land costs in Istanbul are quite high compared to Sakarya Province. The remaining criteria of their study have a similar order of importance to the corresponding criteria in the current study.

5. Conclusion

The whole world has made intense efforts while struggling with the COVID-19 pandemic to minimize its damage. During the fight against the pandemic, the physical infrastructure of general hospitals such as ICU’s has been shown to be insufficient. The aim of this study is to determine the optimal location selection for a pandemic hospital and reveal the factors that affect the decision. For this purpose, the Analytical Hierarchy Process approach was used. The application of the approach was planned as a case study. In order to score the criteria, pairwise comparison questionnaires were completed by 23 experts. The inconsistency of the completed questionnaires was checked and they were validated. The findings of the study show that the *Erenler* district is the most optimal location for a potential pandemic hospital. In addition, the most important three main criteria that affect the location selection of the pandemic hospital are *Risk*, *Accessibility*, *and Opportunities and threats*, respectively. A sensitivity analysis was also conducted in order to observe the reaction of the model in changing environmental conditions. The results of the sensitivity analysis show that the importance order of the model outputs is robust against radical changes. Consequently, the study proposed a valid Analytical Hierarchy Process-based decision support framework approach for selecting a pandemic hospital location. The proposed model will provide decision support to healthcare managers and decision-makers.

For further studies, researchers can reconsider the problem by using integrated multi-criteria decision-making approaches such as AHP-VIKOR and AHP-TOPSIS. Moreover, it can be integrated with systems using real data such as geographic information systems. Also, a fuzzy AHP approach can be used with fuzzy sets for uncertainty. In addition, integrated multi-criteria decision-making such as hesitant fuzzy AHP and spherical fuzzy AHP approaches can be applied using hesitant fuzzy or spherical fuzzy sets.

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