REGIONAL COVERAGE OF SCIENCE CENTERS IN TURKEY

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REGIONAL COVERAGE OF SCIENCE CENTERS IN TURKEY

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Submitted by **Özgün TÜRÜDÜ**

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ABSTRACT

REGIONAL COVERAGE OF SCIENCE CENTERS IN TURKEY

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In 2011, Turkish Supreme Council for Science and Technology decided to establish Science Centers with TÜBİTAK's support in all the metropolitan municipalities by 2016 and in all provinces of Turkey by 2023. Since the budgets of Science Centers are high and they are attracting visitors from other provinces, an additional decision was taken in 2016 to establish Science Centers in prioritized regional centers. The objective of this thesis is to determine the locations of Science Centers in Turkey considering the new criteria defined in the additional decision using integer and mixed integer programming models such as *p*-median, *p*-dispersion, and a multicriteria model. A hybrid model was proposed to utilize *p*-median and multicriteria model together. *P*-median model and hybrid model take into consideration population density of provinces' and distance criteria. *P*-dispersion model, and the multicriteria approach take into consideration only the distance criterion. Location of existing five science centers are included in all models. Models are solved for varying *p* (e.g. number of science centers) values of 5, 10, 13, 15, 20, 25 and 30. Four performance criteria were determined and solutions of the models are compared to each other. Cities selected using different models are compared. To

the best of our knowledge, this thesis is the first study about science center location problem in the literature.

Keywords: science center location, public facility location, *p*-median problem, *p*-dispersion problem

ÖZ

TÜRKİYE'DE BİLİM MERKEZLERİNİN BÖLGESEL KAPSAMASI

TÜRÜDÜ, Özgün

Yüksek Lisans, Endüstri Mühendisliği Anabilim Dalı

Tez Yöneticisi: Doç. Dr. Mustafa Alp ERTEM

Eylül 2017, 62 sayfa

2011 yılında Bilim ve Teknoloji Yüksek Kurulu TÜBİTAK desteği ile 2016 yılı itibarıyla tüm büyükşehirlerde, 2023 yılı itibarıyla tüm illerde bilim merkezi kurulmasını kararlaştırmıştır. Mevcut bilim merkezlerinin bütçelerinin yüksek olduğu ve özellikle çevre illerden de ziyaretçi çektiği göz önüne alınarak bilim merkezlerinin öncelikli olarak belirlenecek bölgesel merkezlerde kurulmasına yönelik 2016 yılında ek karar alınmıştır. Bu tezde ek kararda tanımlanan kriterler göz önüne alınarak bilim merkezlerinin Türkiye'deki yerleşim yerlerinin belirlenmesi amaçlanmıştır ve sonuçları elde etmek için matematiksel modeller tanımlanmıştır. *P*-ortanca modeli, *p*-saçınım modeli, ençoktoplam saçınım modeli ve çok kriterli bir yaklaşım uygulanmıştır. *P*-ortanca ve çok kritlerli yaklaşımı bir araya getiren yeni bir birleşik model önerilmiştir. *P*-ortanca ve birleşik model illerin nüfus yoğunluğu ve mesafeyi dikkate almaktadır. *P*-saçınım modeli, ençoktoplam saçınım modeli ve çok kriterli model sadece mesafeyi göz önüne almaktadır. Mevcut bilim merkezlerinin bulunduğu şehirler tüm modellere eklenmiştir. Modeller, farklı *p* (izin verilen bilim merkezi sayısı) değerleri 5, 10, 13, 15, 20, 25 ve 30 alınarak çözülmüştür. Dört performans kriteri belirlenerek sonuçlar karşılaştırılmıştır. Tüm modeller için seçilen şehirler raporlanmış ve karşılaştırılmıştır. Şu andaki en iyi bilgimize göre bu tez, bilim merkezi yerleşim yerinin belirlenmesi konusundaki ilk çalışmadır.

Keywords: bilim merkezi tesis yerleşimi, kamu tesis yerleşimi, *p*-ortanca problemi, *p*-saçınım problemi

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TABLES

CHAPTER 1

1. INTRODUCTION

Facility location is a critical decision for all companies, governments, entrepreneurs, and non-governmental organizations. As Owen and Daskin (1998) point out, locating a facility is a costly and time sensitive process including determination of location, planning capacity, and distributing a significant amount of capital. In addition to that, it is expected that the facility to be long-lasting to satisfy the needs of people and the objectives of decision-maker in the long term. It is obvious that random facility location decisions without a socio-economic and scientific approach do not provide an effective solution. Thus, facility location decision can be stated as a fundamental decision and without a decent location it is probable that people lose money, time, and lives (e.g. because of a wrong ambulance or a fire station location). Location analyses encompass modelling, formulating, and finding a solution of problems to locate facilities in each space (Revelle and Eiselt, 2005).

Facility location problem can be traced back to the beginning of the 20^{th} century. Weber (1909) proposed the Euclidean spatial median problem whose work constitutes the roots of location theory and modeling (Hale and Moberg, 2003), (Daskin, 2008). He considered locating problem of a single facility for the aim of minimizing the total travel distance between the site and customers (Daskin, 2008). Hotelling investigated two facility location on a line. In this problem customers are allocated uniformly along the line, customers visit the closer of two facilities; vendor’s objective is maximizing the market share (Daskin, 2008). Hakimi (1965) studied *p*-median problem on a network in 1965 and tried siting police stations in a highway system and switching centers in a communications network (Owen and Daskin, 1998).

Four components describing location problems can be summarized as (1) customers that are settled in regions, (2) facilities to locate, (3) space where customers and facilities are placed, and (4) a metric to indicate distances and time between facilities and customers (Revelle and Eiselt, 2005). Examples of facilities in public sector can be given as hospitals, fire stations, schools, police stations, *etc*. whereas in private sector as stores, factories, warehouses, *etc*. These two sectors differentiate from each other based on their objectives. Serra and Marianov (2004) indicates that the main criteria for private sector are maximizing the profit and having larger market share than their competitors whereas the main criteria for public sector are efficiency, equity, minimizing the social cost and universality of service. McAllister (1976) investigated equity and efficiency criteria for public facilities. He studied theoretical and operational concepts for evaluating these criteria (McAllister, 1976). Different objectives of public and private sectors require developing mathematical models with different objective function and constraints. Batta *et al*. (2014) studied dispersion, population, and equity criteria for locating public facilities. There are many facility location studies in the literature that guide applications. For instance, Antunes (1999) proposed a network of sanitary landfills and transfer stations covering the whole region to solve the solid waste sector problems in Portugal. He proposed a mixed-integer optimization model that combines *p*-median and a capacitated-facility-location model to determine the network (Antunes, 1999). Larson studied hypercube queuing model for the aim of analyze vehicle location and response district design problems in urban emergency services (Larson, 1974). Some police departments used that study for vehicles to make suggestion of locations and strategies of deployment (Batta *et al.*, 2014).

There are many types of public facilities in Turkey such as hospitals, schools, museums, libraries, zoos, municipal buildings, *etc*. Recently, Science Centers are established in Turkey by governmental support. Five Science Centers funded jointly by local municipalities and the Scientific and Technological Research Council of Turkey (TÜBİTAK) started to accept visitors. A large amount of capital (i.e. 155,5 Million TL) was spent for these Science Centers as of 30 November 2015. Even though Turkish Supreme Council for Science and Technology decided to open Science Centers in all metropolitan municipalities (30 cities in total) by 2016 in an earlier decision, it is figured out that opening Science Centers are costly investments and that target was revised. Based on these facts, at the 29th Meeting of the Turkish Supreme Council for Science and Technology on 17th February 2016 it was decided to open new Science Centers in prioritized regional centers by considering some criteria such as cities' population, distances to the existing Science Centers, and possibility of using existing buildings after restoration. Science Centers' locations are critical because of the limited budget assigned for this purpose. It is also important to underline the effective use of governmental resources since the government income is constituted from citizens' tax. To the best of our knowledge, Science Center location selection problem has not been investigated in the literature. Thus, the objective of this thesis is determining Science Center locations in Turkey by utilizing public facility location models in the literature and developing models considering the criteria of the prioritized regional Science Centers.

Public facility location selection models are investigated here, because science centers are opened by a governmental institution (TÜBİTAK) and corresponding local municipalities. *P*-median, *p*-dispersion, multicriteria models from literature are used and a hybrid model is proposed. *P*-median model is used to minimize the sum of demand weighted distance. It can be used for the facilities that increase of travel distance affect the accessibility and decrease the effectiveness of facility location such as hospitals (Owen and Daskin, 1998). This model is applied for the aim of minimizing the sum of the distances that people travel to science centers. It causes to open science centers in highly-populated cities to prevent large number of people to travel long distances. *P*-dispersion problem aims to maximize minimum separation distances between opened facilities. It is used to locate facilities that are dangerous to be close to each other such as nuclear power plants. It is also used for franchises to prevent these franchise stores to serve the same members in this system (Kuby, 1987). This model locates science centers as far as from each other and put forward minimum separation distance between science centers. Multicriteria model maximizes the sum of distances between opened facilities while preserving maximin distance from the *p*-dispersion model. This model was used to minimize the sum of distances between science centers and preserve the minimum separation distance. The solutions of *p*-dispersion and multicriteria model are compared to each other by pre-determined performance metrics. A hybrid model is proposed and the objective function of this model is the same with the *p*-median model. This model aims to minimize the sum of travel distances of people traveling to science centers and it also preserve the minimum separation distance between science centers. This model considers distance and population of cities and it does not locate science center closer to each other than *p*-dispersion solution.

This thesis consists of six sections. Section 2 focuses on literature review of facility location selection methods and facility location selection methods at public sector. Section 3 includes Science Centers' brief history, Science Centers' current situation in Turkey and Science Center facility location problem. Section 4 explains mathematical models' notations and formulations for science center location problem. Section 5 is devoted to the application of mathematical models. The Turkish Science Center location problem data from real life are used to solve the mathematical models. Each solution's statistics are given and discussed in this section. Section 6 summarizes the study and its conclusion. The thesis ends with the possible directions for future research.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Facility location selection models in public sector

In the literature, facility location problem is discussed widely. Daskin (2008) made a taxonomy of location models. Taxonomy of location models and specifically of discrete models are given in Figure 1 based on Daskin (2008).

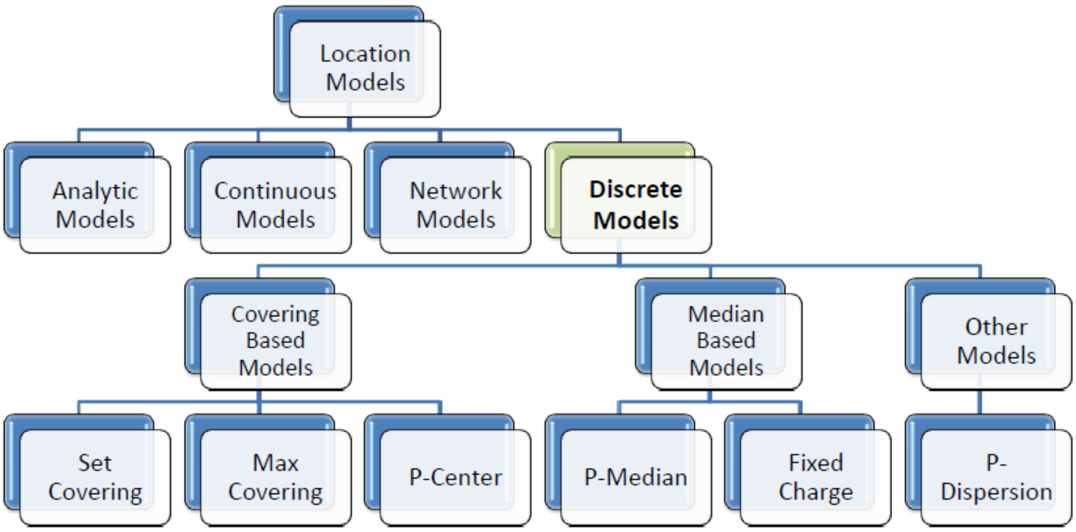


Figure 1: Taxonomy of Location Models

Location models are analyzed in four major sections according to Daskin's classification. Analytic models assume that demand has a typical distribution and facilities can be located at any place in the area given. In continuous models, demand occurs at only discrete points. Numerical calculus techniques and continuous optimization are mostly used in solving analytic models and continuous models, respectively. Demands and facilities are located on a network which is defined by nodes and links in network models. Network models are solved using specialized algorithms. There is not a restriction about distances or costs of traversing the path in discrete models. Typically, nodes show the demand points and facilities could be located at some potential pre-determined locations. Science center location problem can be investigated under discrete location models class considering the demand and facility locations' characteristics. Therefore, we explain discrete location models in more detail.

Under discrete location models covering-based, median based, and other models exists. Covering-based models aim to cover demand points by satisfying some type of a coverage distance criterion. These models can have different objectives. Set covering model's purpose is minimizing the number of facilities while covering all demands. Maximum covering model's objective is maximizing the amount of covered demands using a specific number (usually denoted by *p*) of facilities. *P*-center model aims to minimize the coverage distance and it ensures covering all demands by a certain number of facilities.

Median-based models do not deal with covering all demands. These types of models minimize the average distance between facilities and demands by considering the demand weight. *P*-median minimizes the average distance between demands and the nearest facilities. *P*-median is an NP-hard problem and it is difficult to reach an optimum solution in a reasonable time if the problem size is large. Fixed charge model aims to minimize the fixed facility opening cost and transportation cost. Under other models' category *p*-dispersion model exists. *P*-dispersion model's objective is maximizing the distance between all pairs of facilities (Kuby, 1987). Because of that each facility is opened as far as possible to each other.

Serra and Marianov (2004) provide a literature review of public facility location problems. Among the seminal studies, Gleason (1975) used set covering model to locate bus stops. ReVelle *et al*. (1976) used set covering model and minimized the quantity of emergency vehicles while serving the entire population by at least one vehicle. Eaton *et al*. (1981) studied to locate health clinics and maximal covering location model was used in this work. Moore and Revelle (1982) used maximal covering location model for hierarchical health services. Later, Batta *et al*. (2014) studied public facility location problem comparing several objectives. They investigated that how bad a location decision can be made by adopting dispersion, population, and equity criteria. New formulations used to analyze the worst-case performance.

Six studies are reported in a special issue (Bruno and Genovese, 2016). They address location analyses for public sector to make decision in uncertain situations. Bruno *et al*. (2016) investigate institutional merging because of the reductions of public expenditure for education. They provide two mathematical models for decision making and test them. Cao *et al*. (2016) examine donation of breastmilk supply chain. In this problem supply and demand are uncertain. Chaudhary *et al*. (2016) study fire station location in a highly populated area. Multi-criteria decision analysis is made by considering four criteria: distance from roads, distance from rivers, land cover, and density of population. Murray and Feng (2016) worked on the issue of street lighting in urban areas. They developed a systematic assessment procedure for re-evaluation. Şahin *et al*. (2016) studied removal of debris in disaster affected zones. They developed a mathematical model for the aim of selecting paths to deliver emergency materials while debris are on the ground. Sterle *et al*. (2016) presented a study about placing a set of portable *variable message signs* within an urban transportation network.

2.2. Science centers in the education literature

Keyword search from academic databases for “science centers” resulted mostly with educational studies. Related literature from an educational standpoint are examined to understand the characteristics of science centers. Ferry (1995) investigated teacher education experience in science centers. Pre-service teachers guide children to improve their own teaching skills. Rennie and McClafferty (1995) investigated if interactive science and technology centers, museums, aquaria, and zoos support learning for target school groups.

Falk and Storksdieck (2005) studied free choice science learning. They investigated what independent factors individually affect learning outcomes when not studying isolated. They also investigated whether *contextual model of learning* helps understanding from museums. Contextual model of learning is defined as "a device for organizing the complexities of learning within free choice setting" by Falk and Dierking (2000). The study was conducted with 217 randomly chosen adult visitors. Pre-post interviews, observational, and behavioral measures derived from science center experience. Eleven key factors are investigated that influence museum learning experiences. It is shown that these factors influence learning outcomes separately. The contextual model of learning framework helped exposing complexities of learning from science centers. Learning in personal context in free choice science and national history museums are studied by Bamberger and Tal (2007). Four different museums visited by 750 students in class visits. Three levels of choice from no choice to free choice were defined. No choice means, a guide leads the students and students are not allowed to visit the museum by themselves. Free choice means that students are free to explore the museum at some stages. The objective of the study was to understand the effect of the choice level on learning. Museum learning data collected by observations, semi-structured interviews, and museum worksheets. It was found that limited choice museum experiment support learning better than other types (*e.g.* free choice and no choice).

In the educational literature on science centers, it is seen that learning context, factors that effects learning are explained in different point of views. Studies widely focus on children and young visitors. It was seen that people from with different age, sex, and level of education people visit these centers.

To sum up, facility location problem was explored in literature to find a solution to the science center location problem. Daskin's classification, public facility location studies and related special issues were investigated. Discrete models were studied in detail, specifically *p*-median and *p*-dispersion models. Science centers were searched from academic databases and several educational studies were reached. According to these studies, learning levels, factors, and teaching science in a science center were found as relevant topics. To the best of our knowledge, there is not any study focusing on selecting the location of a science center in the literature.

CHAPTER 3

3. PROBLEM DESCRIPTION

The First Science Center in the world, namely Urania, was opened in 1888 in Germany and it survived in its original form until 1928. The first modern science center “Frank Oppenheimer’s Exploratorium” in San Francisco was opened in 1969 (History of the Science Center, 2017). Popularity of interactive science centers and museums has increased (Ferry, 1995) in the last two decades. Science centers have been discussed in the literature frequently from an educational standpoint. For instance, Rennie and McClafferty (1995) investigated whether Science Centers affect learning and the ways to promote student engagement in science. However, to the best of our knowledge, Science Center location problem has not been discussed thoroughly in the literature.

The first Science Center in Turkey, namely “Feza Gürsey Science Center”, was opened on 23 April 1993 by Ankara Metropolitan Municipality (Feza Gürsey Bilim Merkezi, 2017). There are several Science Centers in Turkey of various sizes and ownerships, in this thesis we focus on the Science Centers that are opened using TÜBİTAK funding.

At Turkish Supreme Council for Science and Technology’s 23rd Meeting in 2011, increasing the number of Science Centers was brought to agenda. It was stated that Science Centers put people together who are in different age groups and have different experience, make science and technology understandable and accessible for society, promote visitors’ exploring and experimentation via interactive teaching, aim to augment the importance of science and technology, embody empirical and applied activities. It was also indicated that Science Centers in different countries become attraction centers for the locations nearby. People can experience the enjoyable part of science and develop increasing interest in science. With the foresight of science centers would have a critical role to increase attention around science culture, it was targeted to establish Science Centers and increase their number in Turkey. With this motivation a decision was taken. According to the decision “Orienting Young People to R&D Fields” strategy was included into the Science and Technology Human Resource Strategy and Action Plan 2011-2016. It was indicated that this was critical and under this strategy “Increasing popular science activities, augmenting curiosity to scientific activities for primary and secondary education” action plan was taken. In line with this action plan it was decided to start studies establishing Science Centers with TÜBİTAK’s support in all the metropolitan municipalities by 2016 and in all provinces of Turkey by 2023 which is expected to increase curiosity and attention towards science especially among children and young people and cause better use of technology. Although there are 30 metropolitan municipalities in Turkey, only five Science Centers (Konya, Kocaeli, Kayseri, Bursa, Elazığ) have been established until 2017, some of which are not officially accepting visitors (Figure 2). Pre-contracts have been signed with municipalities of eight other cities (Adana, Antalya, Balıkesir, Erzurum, Gaziantep, Samsun, Tokat, and Şanlıurfa).

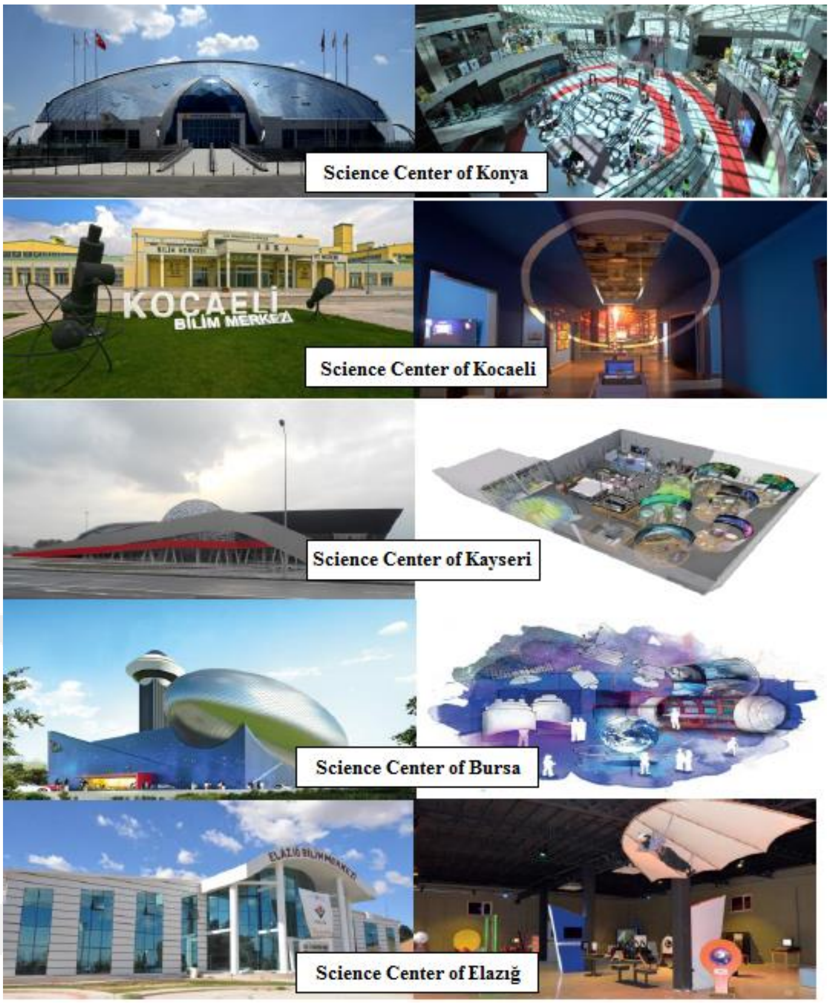


Figure 2: Science Centers Opened by Support of TÜBİTAK in Turkey

At the 29th Meeting of the Turkish Supreme Council for Science and Technology on 17th February 2016, an additional decision on Science Centers was taken as given below.

> *For the aim of accelerating and facilitating to increase the number of Science Centers regarding the fact that the budgets of Science Centers are high and Science Centers are attracting visitors from other provinces around their region, it is decided for new Science Centers to make contracts concerning the following.*
>
> *- Science Center will be opened in prioritized regional centers by considering some factors such as cities' population, distances to the existing Science Centers and using existing buildings after restoration.*
>
> *- Planning studies to determine the location of regional centers will be executed by TUBITAK and presented at the 30th meeting of Turkish Supreme Council for Science and Technology.*

It was understood that opening too many Science Centers is difficult because of their budget. Existing Science Centers' contract budget increased dramatically by November 30, 2015. Cities' Municipalities met additional budget. Science Centers' contract budgets and reached budgets are given in Table 1. Another finding stated in the document is that the Science Centers are attracting visitors from other cities.

Table 1: Science Centers' Contract Budgets and Reached Budgets

Science Center	Konya Science Center	Kocaeli Science Center	Kayseri Science Center	Bursa Science Center	Elazığ Science Center
Contract Date	September 4, 2008	September 3, 2012	March 11, 2013	February 4, 2014	May 21, 2015
Contract Budget	12 Million TL	25 Million TL	19 Million TL	16 Million TL	3 Million TL
Budget (November 30, 2015)	54 Million TL	28,5 Million TL	30 Million TL	40 Million TL	3 Million TL
Increase Rate	350 %	14 %	57,9 %	150 %	0 %

These facts in the additional decision reveal that there is a need for determining locations of science centers considering some of the factors defined in the additional decision. We investigated the facility location problem in the literature, but we were not able to find a study about Science Center facility location problem. Therefore, we decided to propose a solution to this public facility location problem. We aim to determine the number of Science Centers and their locations in Turkey by taking population of cities, distances between cities and Science Centers into consideration. It is expected that the solution will enable to determine science centers locations and increase the reach of Science Centers to diverse populations.

CHAPTER 4

4. MODEL FORMULATION

As it is defined in the additional decision it is decided to consider some factors to determine the Science Centers facility location in this thesis as follows. Population of cities, distance of all cities to the existing science centers and distance of Science Centers to each other are considered. It is decided to ignore the last criterion which is using existing buildings after restoration in this thesis since we are not able to get information about those facilities.

Notation of models is given below.

$$X_j = \begin{Bmatrix} 1, \text{if a facility is located at node } j \\ 0, \text{otherwise} \end{Bmatrix}$$

$$Y_{ij} = \begin{Bmatrix} 1, \text{if demand at node } i \text{ is served by a facility at node } j \\ 0, \text{otherwise} \end{Bmatrix}$$

$$Z_{ij} = \begin{Bmatrix} 1, \text{if facilities are located at both } i \text{ and } j \\ 0, \text{otherwise} \end{Bmatrix}$$

D = smallest separation distance between any pair of open facilities

h_i = demand node for city i

p = number of facilities to be located

d_{ij} = distance between demand node i and candidate site j

d_{opt} = the optimal maximin dispersion distance from a previous run of the *p-dispersion model.*

n = number of potential facility sites

N = set of potential facility sites

M = a very large number

4.1. *P*-median model

$$\text{Minimize} \sum_{i \epsilon I} \sum_{j \in J} h_i d_{ij} Y_{ij} \qquad (1)$$

s.t.

$$\sum_{j \in J} Y_{ij} = 1 \qquad \forall\, i \in I \qquad (2)$$

$$Y_{ij} - X_j \leq 0 \qquad \forall\, i \in I, \forall\, j \in J \qquad (3)$$

$$\sum_{j \in J} X_j = p \qquad (4)$$

$$X_j \in \{0, 1\} \qquad \forall\, j \in J \qquad (5)$$

$$Y_{ij} \in \{0, 1\} \qquad \forall\, i \in I, \forall\, j \in J \qquad (6)$$

Here, $i \in I$ is the index for demand nodes, and $j \in J$ is the index for candidate facility location sites. *P-median model* objective function (1) minimizes sum of demand-weighted distance between all demand nodes and all selected sites. Constraints (2) require demand at node *i* is satisfied by a candidate facility *j*. Constraints (3) require that the demand at node *i* can be assigned only to an opened facility at node *j*. Constraint (4) shows that exactly *p* facilities are located. Constraint (5) limits the value of X_j as a binary variable. Constraint (6) limits the value of Y_{ij} as a binary variable.

4.2. *P*-dispersion model

Maximize D (7)

s.t.

$$\sum_{j=1}^{n} X_j = p \quad (8)$$

$$D \leq d_{ij}\left(1 + M(1 - X_i) + M\left(1 - X_j\right)\right) \quad \text{for all } i, j \in N \mid i < j \quad (9)$$

$$x_i \in \{0, 1\} \quad \text{for all } i \in N \quad (10)$$

Here, both $i \in N$ and $j \in N$ are the indices for candidate facilities. *P*-dispersion model (Kuby, 1987) aims to maximize the minimum separation distance between opened facilities with the objective function (7). Constraint (8) restricts the number of facilities to p. Constraints (9) satisfy that the maximum smallest separation distance between opened facilities must be smaller or equal to the distance between any opened facilities. Distance between facilities (d_{ij}) limits distance D only if both facilities are opened at nodes i and j. Constraints (10) limit the value of X_j value as a binary variable.

4.3. Multicriteria approach (p-dispersion and maxisum dispersion)

$$\text{Maximize} \sum_{i=1}^{n} \sum_{j=i+1}^{n} Z_{ij} d_{ij} \quad (11)$$

$$\sum_{i=1}^{n} X_i = p \tag{12}$$

$$Z_{ij} \leq X_i \quad \text{for all} \quad i, j \in N |\ j > i \tag{13}$$

$$Z_{ij} \leq X_j \quad \text{for all}\ i, j \in N |\ j > i \tag{14}$$

$$D \leq d_{ij}\left(1 + M(1 - X_i) + M\left(1 - X_j\right)\right) \quad \text{for all} \quad i, j \in N \mid\ i < j \tag{15}$$

$$D \geq d_{opt} \tag{16}$$

$$X_i \in \{0, 1\} \ \text{for all}\ i \in N \tag{17}$$

Multicriteria approach brings *p-dispersion* and *maxisum dispersion* models together. The model maximizes the sum of distances between opened facilities while preserving maximin distance from the *p-dispersion model*. Objective function (11) maximizes the sum of distances between opened facilities. Constraint (12) shows the number of facilities *p*. Constraint (13) and Constraint (14) limits the Z_{ij} value. Only if facilities at *i* and *j* are both opened, then Z_{ij} takes the value 1. Constraint (15) shows that maximum smallest separation distance between opened facilities must be smaller or equal to the distance between any opened facilities. Constraint (16) shows that D value must be greater than or equals to d_{opt} - optimum maximin dispersion value that is taken from dispersion problem's solution. Constraint (17) limits the value of X_i as a binary variable.

4.4. Hybrid model (*p*-median and multicriteria)

$$\text{Minimize} \sum_{j \in J} \sum_{i \in I} h_i d_{ij} Y_{ij} \qquad \forall i \in I, \forall j \in J \tag{18}$$

s.t.

$$\sum_{j \in J} Y_{ij} = 1 \qquad \forall\, i \in I \qquad (19)$$

$$Y_{ij} - X_j \leq 0 \qquad \forall\, i \in I, \forall\, j \in J \qquad (20)$$

$$\sum_{j \in J} X_j = p \qquad \forall\, i \in I \qquad (21)$$

$$D \leq d_{ij} \left(1 + M(1 - X_i) + M\big(1 - X_j\big)\right) \quad \text{for all} \quad i, j \in N \mid i < j \qquad (22)$$

$$D \geq d_{opt} \qquad (23)$$

$$X_j \in \{0, 1\} \qquad \forall\, j \in J \qquad (24)$$

$$Y_{ij} \in \{0, 1\} \qquad \forall\, i \in I, \forall\, j \in J \qquad (25)$$

Hybrid model brings *p-median* and *multicriteria approach* together. Objective function (18) minimizes sum of demand-weighted distance between all demand nodes and all selected sites. Constraints (19) require each demand at node *i* is satisfied by a total of selected sites *j*. Constraints (20) require that the demand at node *i* can be assigned only to an opened facility at node *j*. Constraint (21) shows that exactly *p* facilities are located. Constraint (22) shows that maximum smallest separation distance between opened facilities must be smaller or equal to the distance between any opened facilities. Constraint (23) shows that D value must be greater than or equal to d_{opt} - optimum maximin dispersion value that is taken from dispersion problem's solution. Constraint (24) limits the value of X_j as a binary variable. Constraint (25) limits the value of Y_{ij} as a binary variable.

CHAPTER 5

5. EXPERIMENTAL STUDY

Science center location problem was solved with mathematical models given in Chapter 4. Different *p* values were taken into consideration while solving mathematical models. *P* values are explained in detailed below:

- For *P*=5 (5 Existing science centers)
- For *P*=10 (5 Existing science centers + 5 new science centers)
- For *P*=13 (5 Existing science centers + 8 cities have pre-contract)
- For *P*=15 (5 Existing science centers + 10 new science centers)
- For *P*=20 (5 Existing science centers + 15 new science centers)
- For *P*=25 (5 Existing science centers + 20 new science centers)
- For *P*=30 (5 Existing science centers + 25 new science centers)

Assumptions and the sources of the data set are explained as follows.

- If a facility is decided to be opened, it will not be closed. In all mathematical models existing science centers (Konya, Kocaeli, Kayseri, Bursa, Elazığ) were added to the mathematical models to keep them opened.
- Cities resulting from mathematical model solutions for different *p* values are independent from each other. For example, cities *p*=20 solution may not contain all the cities arising from *p*=15 solution.
- Demands were taken as cities' population. Provinces' populations were taken from TUIK website for 2015 (Provinces' Population by Years, 2016). 2015 population was used because it was reached when experimental study was first applied.

- *D* (Minimum separation distance between science centers) value was calculated in *p*-dispersion model. Distances between five (5) existing science centers were not added to the mathematical models to prevent limiting *D* value.
- Distances between cities were taken from General Directorate of Highways website (Distances Chart Between Provinces, 2016).

5.1. Performance criteria

Models were coded in GAMS IDE 2.0.37.11 software and solved using CPLEX Solver 11.0. Each model was solved in minimum 3,7 seconds and maximum 16 minutes 42,9 seconds. Models' solution durations are given in Table 2.

Table 2: Model Solution Durations

	***P*-median model**	***P*-dispersion model**	**Multicriteria model**	**Hybrid model**
***p*=5**	7,082 secs	3,713 secs	11,747 secs	8,003 secs
***p*=10**	7,160 secs	3,822 secs	5,102 secs	8,533 secs
***p*=15**	6,927 secs	4,758 secs	5,636 secs	8,198 secs
***p*=20**	7,239 secs	2 min 55,516 sec	6,440 secs	8,331 secs
***p*=25**	6,958 secs	16 min 42,834 sec	34,955 secs	8,083 secs
***p*=30**	6,973 secs	16 min 42,974 sec	12,241 secs	8,601 secs

A PC with "Intel® Core™ i33110M CPU @ 2.40 GHz" processor, 4GB installed memory was used in all of the experiments. It was not meaningful to compare the objective function values to each other because each model aims at a different objective. Because of this reason, four performance criteria were determined to compare solutions. Performance criteria are given and explained in the following.

- **Performance criterion 1:** *Distance between all pairs of science centers*. In the additional decision of 29th Meeting of the Turkish Supreme Council for Science and Technology, it was pointed out that distances to the existing science centers must be considered while opening a new science center. This performance criterion is calculated with minimum, maximum and average distance values to compare the solutions for all pairs of opened science centers (including existing and obtained from the model solution).

- **Performance criterion 2:** *Distance between the closest pairs of science centers.* Distance between the closest science centers was calculated. It provides valuable information to understand maximum and minimum distances between the closest opened science centers.
- **Performance criterion 3:** *Amount of satisfied demand by each science center*. In the mathematical models all cities are assigned to an opened science center. By this criterion the amount of demand satisfied by each science center is calculated for controlling the service level.
- **Performance criterion 4:** *Distance between demand point i and science center j*: Here, the distance between demand point *i* and the science center *j* which serves demand point *i* is calculated. By this criterion traveling distances for visitors of science centers are controlled as another service level.

Every performance criteria could not be used for all models. Performance criteria 3 and 4 could be used only for *p*-median and hybrid model because only these models consider demand. All mathematical models consider distance between cities however *p*-median model does not consider distance between science centers. Only *p*-median and hybrid models consider population of cities. Proposed hybrid model considers all these parameters. Mathematical models and which criterion they satisfy are summarized in Table 3.

Table 3: Parameter and Mathematical Model

	Distance between Cities	**Distance between Science Centers**	**Population of City**
***P*-median model**	✓	x	✓
***P*-dispersion model**	✓	✓	x
Multicriteria model	✓	✓	x
Hybrid model	✓	✓	✓

5.2. *P*-median model solution

P-median problem was solved with the aim of minimizing demand-weighted distance for different *p* values. This model tends to open science centers in big-populated cities to prevent travel of large amount of people to other cities to minimize objective function. As it is expected science centers are opened in big populated cities such as İstanbul, Ankara, etc. for *p* values 15, 20, 25 and 30. Allocation of science centers in Turkey for *p*=15 is given in Figure 3 as an example. *P*-median problem is NP hard, but in our problem mathematical model solved in a reasonable time because data set is for small (i.e. 81 cities). Science centers and the cities which they serve are same colored in the map.

Figure 3: Selected Science Centers According to the *P*-median Model

Performance criterion 1 (distances between all pairs of science centers) is calculated. Statistics are given in Figure 4. According to the solutions, minimum distance between all pairs of science centers stays same until *p*=30 solution and then decreases. Maximum distance between all pairs of science centers increases while *p* increases. It is seen that average distance between science centers increases until *p*=30 solution and then decreases while *p* increases.

To give an example from *p*=15 solution, closest located science centers are Kocaeli and Istanbul with a distance 111 km. Science centers which located furthest are Van and İzmir with the distance 1752 km.

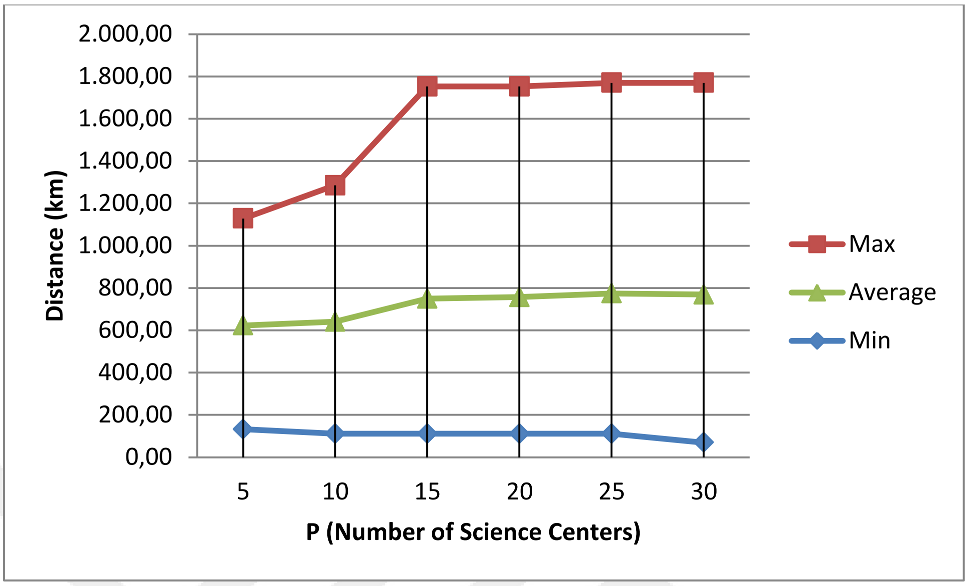


Figure 4: Performance Criterion 1: Distance Between All Pairs of Science Centers According to P-median Model

Performance criterion 2 (distances between the closest pairs of science centers) is calculated and statistics are given in Figure 5. According to the solutions, minimum distance between closest pairs of science centers stays same until *p*=30 and then decreases. Maximum and average distance between closest pairs of science centers decreases while *p* increases.

P=15 solution can be illustrated here. Minimum distance between the closest pairs of science centers is 111 km which refers to distance between Kocaeli and Istanbul. Maximum distance between the closest pairs of science centers is 370 km which refers to the distance between Diyarbakır and Van.

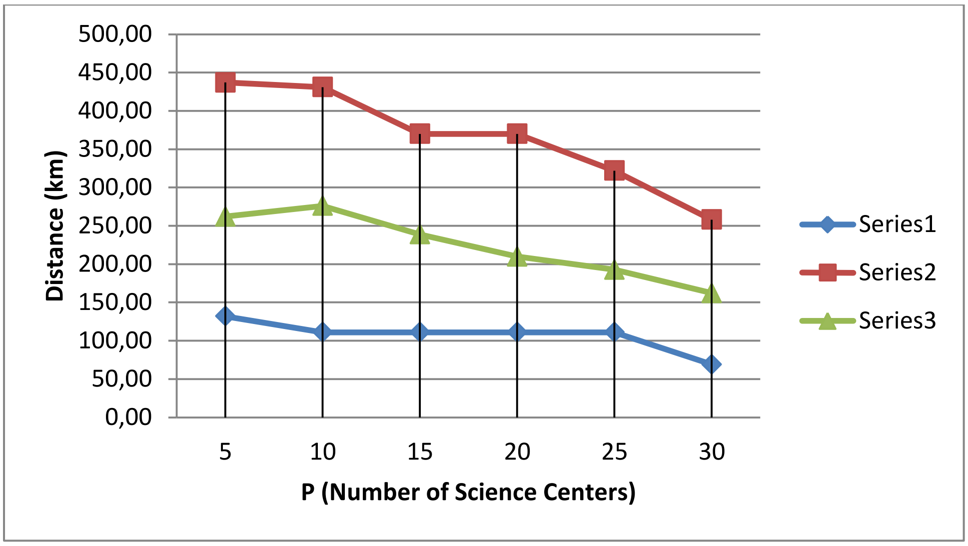


Figure 5: Performance Criterion 2: Distance Between Closest Pair of Science Centers According to the P-median Model

In *p*-median model each city was assigned to a science center. Performance criterion 3 (the total amount of satisfied demand from each science center) is calculated. Statistics are given in Figure 6. Statistics showed that all minimum, maximum, and average total satisfied demand from a science center decreases while *p* increases. Opening science centers allocate the population between these science centers.

According to *p*=15 solution the minimum amount of total satisfied demand is 1.700.468 people. This refers to the existing science center in Elazığ which satisfies the demand of Bingöl, Malatya, Tunceli and its own. Maximum amount of total satisfied demand is 16.344.854 people. This number refers to the proposed science center in İstanbul which satisfies the demand of Edirne, Kırklareli, Tekirdağ and its own, and this value is maximum among other science centers.

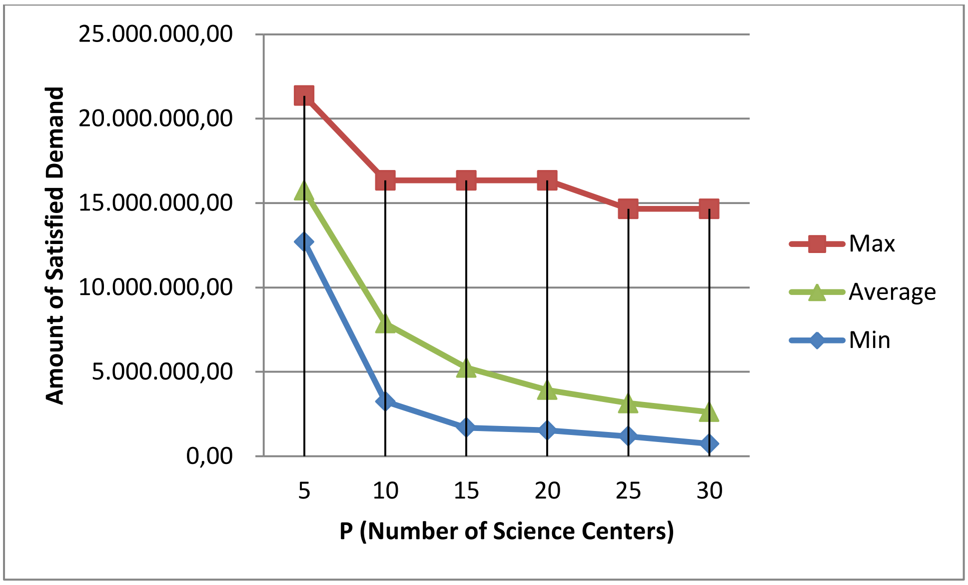


Figure 6: Performance Criterion 3: Amount of Total Satisfied Demand by Each Science Center According to the *P*-median Model

Performance criterion 4 (distances between assigned cities and the science centers) is calculated. Statistics are given in Figure 7. According to the statistics, minimum distance between the demand city and existing science centers is 37 km (*p*=5). Minimum distance between the demand city and science centers is 35 km for *p* values of 10, 15 20, 25 and 30. Maximum and average distance between a demand city and a science center decreases while *p* increases. People travel less distance to reach a science center if more science centers are opened.

For *p*=15 solution minimum distance between the demand city Manisa and a science center in Izmir is 35 km. People from Manisa travel only 35 km to reach Izmir science center. Maximum distance between the demand city Kars and a science center in Van is 365 km. On the average people travel 164,85 km to reach science center.

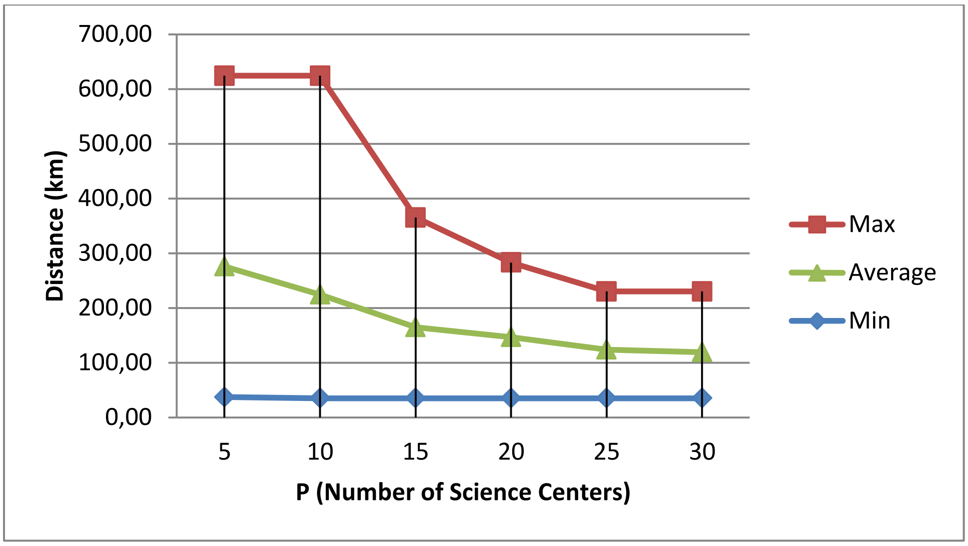


Figure 7: Performance Criterion 4: Distance Between Demand Point *i* and Science Center *j* According to the *P*-median Model

5.3. *P*-dispersion model solution

P-dispersion model is solved to maximize the minimum separation distance between opened science centers. The science centers are located as far from each other as possible. For *p*=5, distance was already determined statistically and the model was not run for this value. Minimum separation distance is 132 km which is the distance between already open science centers in Bursa and Kocaeli. To prevent getting the same minimum separation distance value of 132 km, models were run by excluding the existing science centers distances to each other from the constraint (9) for *p*=10, 15, 20, 25 and 30.

Opened science centers in Turkey for *p*=15 is given in Figure 8.

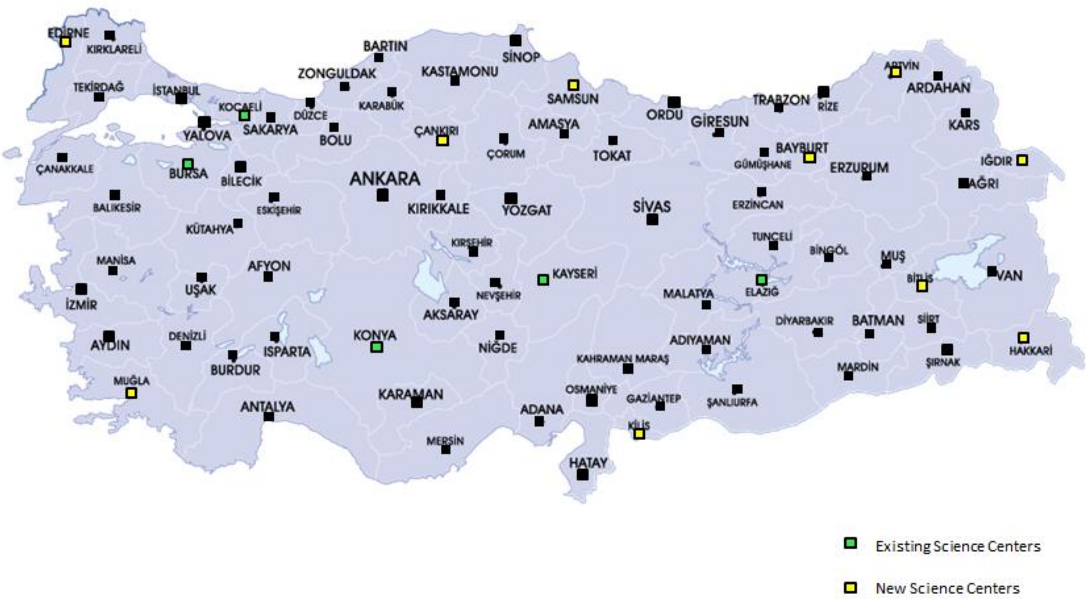


Figure 8: Selected Science Centers According to the *P*-dispersion Model

Maximized separation distances are given in Table 4. Minimum separation distances decrease while *p* increases. The model locates science centers as far as possible. To give an example if 15 science centers was opened closest distance between these science centers would be 328 km.

Table 4: Maximized Minimum Separation Distances Between Science Centers According to the *P*-dispersion Model

P	***D* (km)**
10	438
15	328
20	281
25	218
30	184

Performance criterion 1 is calculated for this model solution. Statistics are given in Figure 9. According to the solutions, minimum distance between all pairs of science centers are the same while *p* increases from *p*=5 to *p*=25 and then distance decreases. Maximum distance between all pairs of science centers fluctuates while *p* increases. This model aims to maximize minimum distance between science centers. Because of this reason average distance between all pairs of science centers decreases while *p* increases and the pattern does not change by the change of *p*. Average distance between all pairs of science centers decreases from *p*=10 to *p*=30 while *p* increases. *P*=5 shows the existing science centers and differs from the pattern.

P=15 solution is explained here as an example. Minimum distance between all pairs of science centers is 132 km which refers to distance between Kocaeli and Bursa. These science centers were not opened according to the model solution. They are already open and constitute the minimum distance. Maximum distance between all pairs of science centers is 2040 km which refers to distance between Edirne and Hakkari. Average distance between all pair of science centers is 879,35 km.

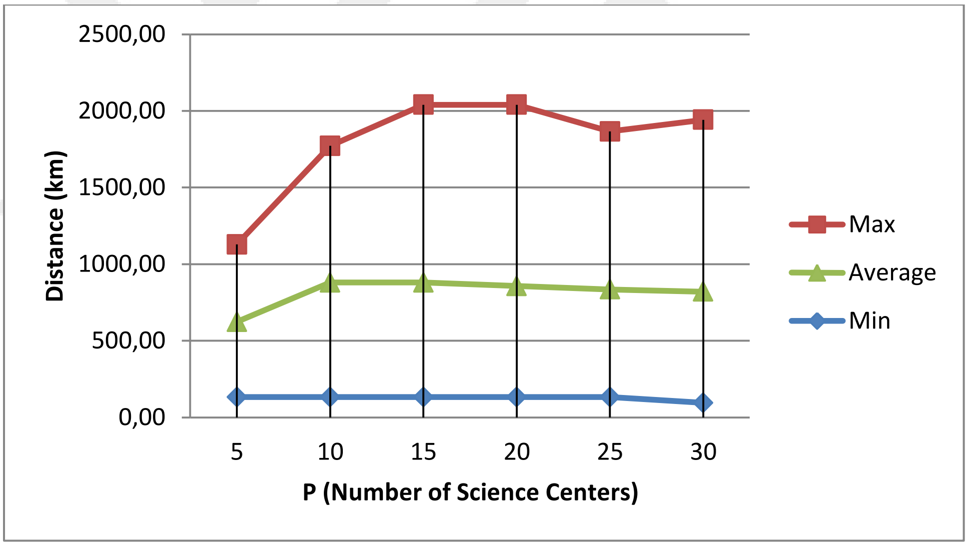


Figure 9: Performance Criterion 1: Distance Between All Pairs of Science Centers According to the *P*-dispersion Model

Performance criterion 2 is calculated. Statistics are given in Figure 10. Minimum distance between closest pairs of science centers is the same from *p*=5 to *p*=25 and then decreases while *p* increases. Maximum and average distance between closest pairs of science centers decreases for *p*=10 to *p*=30 while *p* increases. *P*=5 differs because it shows the existing science centers. This performance criterion shows similar result as performance criterion 1. Distance between science centers decreases while *p* increases.

To give an example *p*=15 solution is explained here. Minimum distance between closest pairs of science centers is 132 km which refers to distance between existing science centers Bursa and Kocaeli. Maximum distance between closest pairs of science centers is 544 km which refers to distance between Bursa and Muğla. Average distance between closest pairs of science centers is 322,40 km.

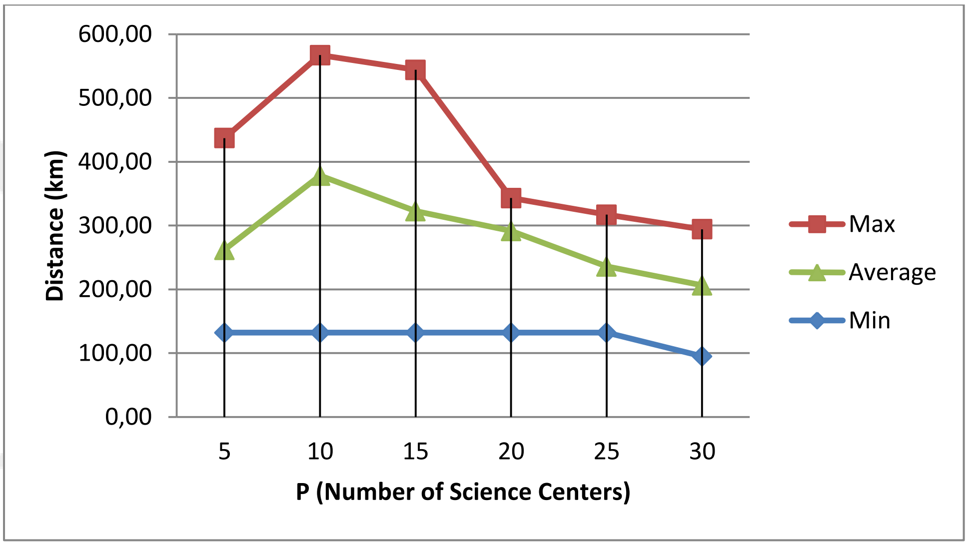


Figure 10: Performance Criterion 2: Distance Between Closest Pair of Science Centers According to the *P*-dispersion Model

5.4. Multicriteria approach (*p*-dispersion and maxisum dispersion) solution

Multicriteria approach was used to maximize the sum of distances between opened science centers while preserving maximin distance from *p-dispersion model*. Minimum distance value between science centers which was calculated by *p*-dispersion model was added to this mathematical model as a constraint. Then the model was solved to maximize sum of the distances between science centers. Models were run by excluding existing science centers distance between each other as it was done in *p*-dispersion model, from the constraint (15) for *p*=10, 15, 20, 25 and 30. Allocation of science centers in Turkey for p=15 is given in figure 11.

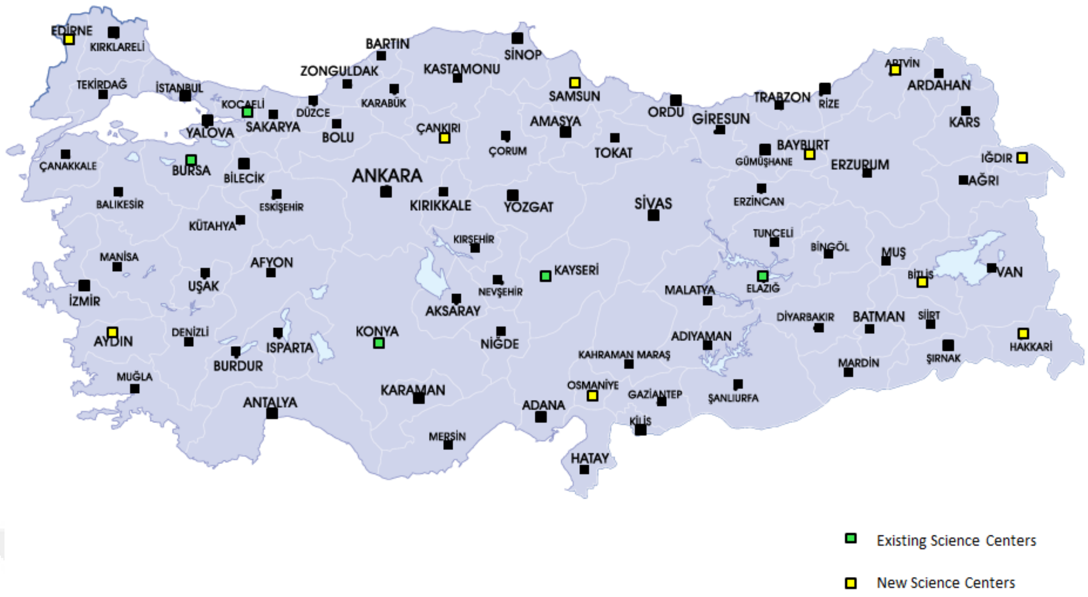


Figure 11: Selected Science Centers According to Multicriteria Approach

According to the multicriteria model, maximized sum of the distances between science centers are given in Table 5. Sum of the distances between science centers increases while *p* increases.

Table 5: Maximized Sum of Distances Between Opened Science Centers According to the Multicriteria Approach

P	Maximized Sum of Distances Between Opened Science Centers (km)	Minimum Distance between Science Centers (calculated in *p*-dispersion model) (km)
10	39.711,00	438,00
15	91.194,00	328,00
20	161.950,00	281,00
25	260.413,00	218,00
30	363.307,00	184,00

Performance criterion 1 is calculated and statistics are shown in Figure 12. Minimum distance between all pairs of science centers are the same for *p*=5, 10, 15, 20, 25 and it increases for *p*=30. Maximum distance and average between all pairs of science centers fluctuates while *p* increases.

P=15 solution is given to give an example here. Minimum distance between all pairs of science centers is 132 km which refers to the distance between existing science centers Kocaeli and Bursa. Maximum distance between all pairs of science centers is 2040 km which refers to the distance between Edirne and Hakkari.

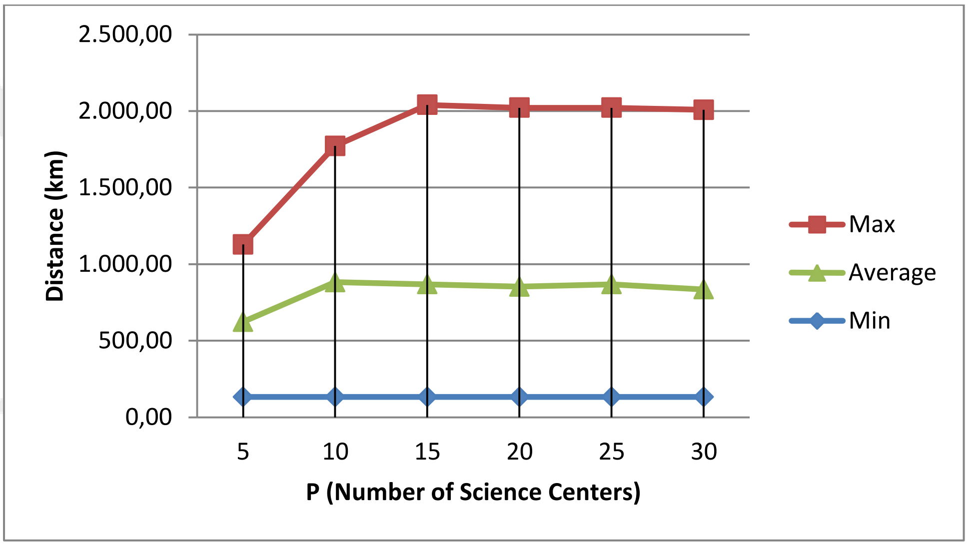


Figure 12: Performance Criterion 1: Distance Between All Pairs of Science Centers According to the Multicriteria Approach

Performance criterion 2 is calculated. Statistics are given in Figure 13. Minimum distance between closest pairs of science centers is the same from *p*=5 to *p*=30. Maximum distance between closest pairs of science centers decreases from *p*=10 to *p*=25 while *p* increases. *P*=5 and 30 differs from this pattern. Average distance between closest pairs of science centers decreases *p*=10 to *p*=30 while *p* increases. *P*=5 differs because it shows the existing science centers.

To give an example *p*=15 solution is explained here. Minimum distance between closest pairs of science centers is 132 km which refers to distance between existing science centers Bursa and Kocaeli. Maximum distance between closest pairs of science centers is 445 km which refers to distance between Aydın and Bursa. Average distance between closest pairs of science centers is 314,53 km.

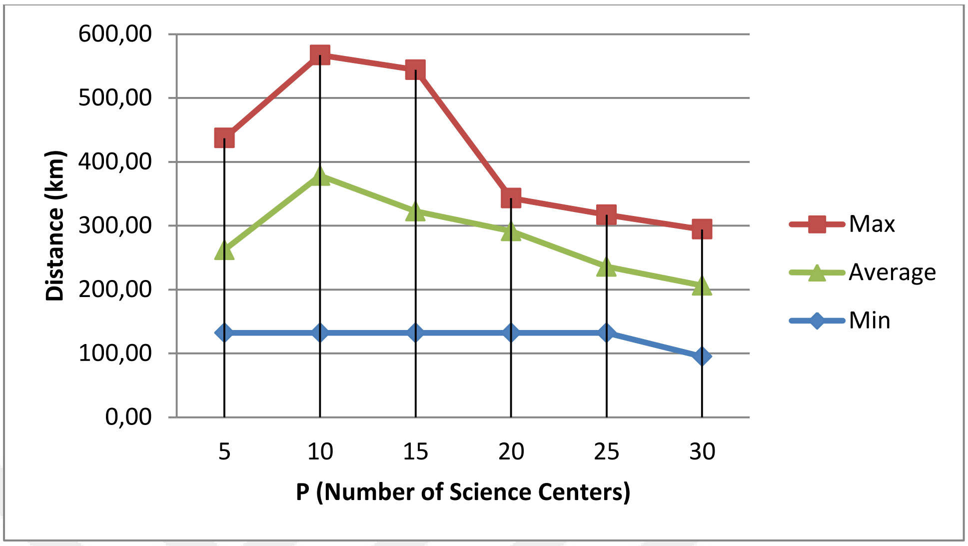


Figure 13: Performance Criterion 2: Distance Between Closest Pair of Science Centers According to the Multicriteria Approach

5.5. Hybrid model (*p*-median and multicriteria) solution

Hybrid model is proposed here to minimize demand-weighted distance for different *p* values while preserving maximin distance from *p-dispersion model*. Constraint (23) was added from p-dispersion model and constraint (24) was taken from multi criteria approach. This model aims to prevent big number of people to travel long distances as *p*-median model. But it also preserves the distance between science centers that comes from *p*-dispersion solution. This model considers population, distance between cities and distance between science centers. Models were run by excluding existing science centers from the constraint (22) for *p*=10, 15, 20, 25 and 30. Allocation of science centers in Turkey for *p*=15 is given in figure 14.

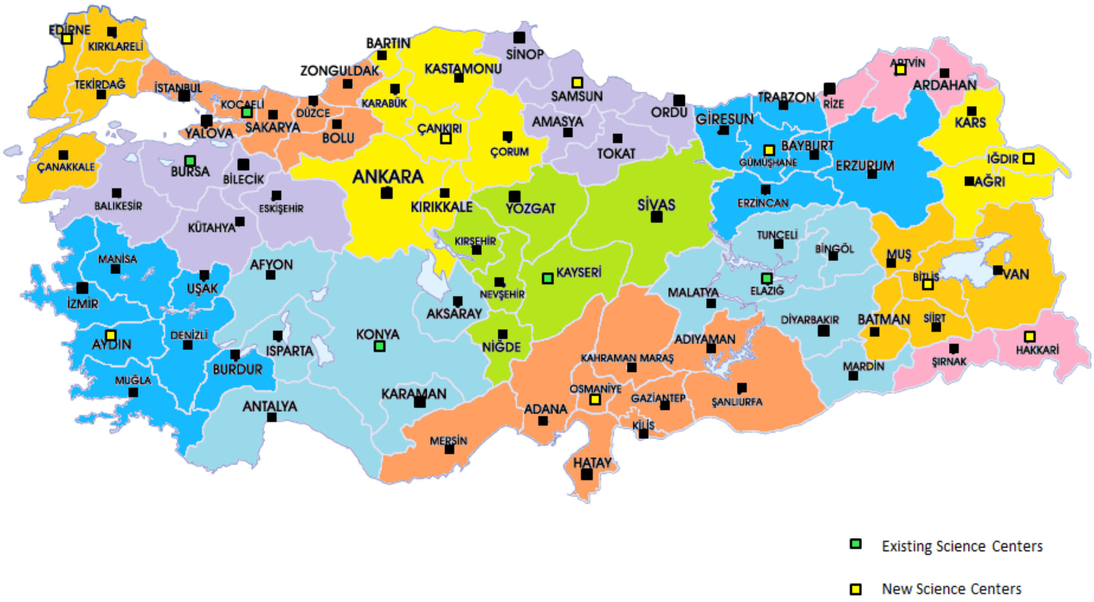


Figure 14: Selected Science Centers According to the Hybrid Model

Science centers and cities which they serve are colored in the map. Statistical results are given.

Performance criterion 1 was calculated. Based on the solutions, minimum distance between all pairs of science centers stays same. Maximum and average distance between all pairs of science centers fluctuates while *p* increases. Average distances do not decrease regularly as p-dispersion model because this model aims to minimize demand-weighted distance while preserving minimum separation distance.

P=15 solution is given in Figure 15 and explained here. According to *p*=15 solution minimum distance between all pair of science centers is 132 km which refers to distance between existing science centers Kocaeli and Bursa. Maximum distance between all pair of science centers is 2040 km which refers to distance between Edirne and Hakkari. Average distance between all pair of science centers is 868,17 km.

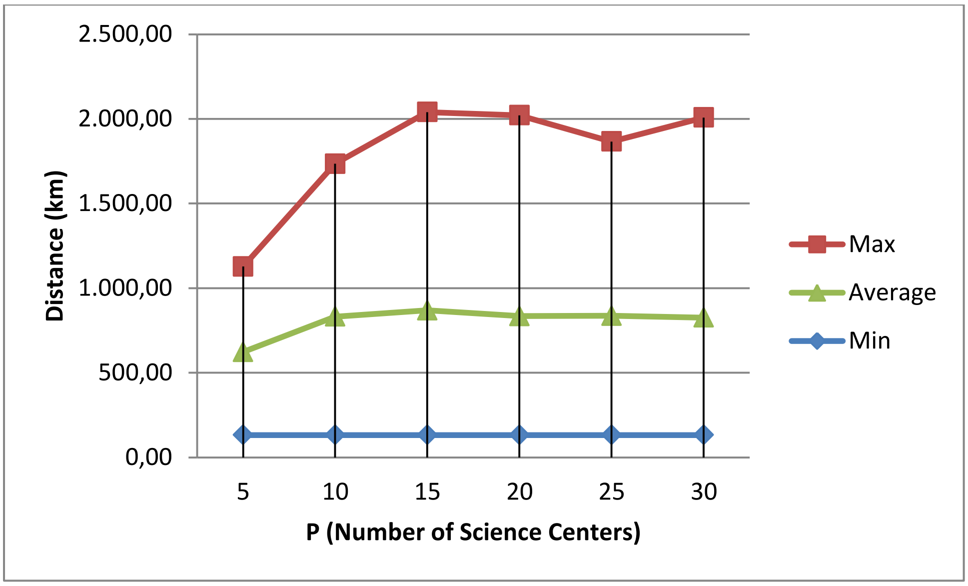


Figure 15: Performance Criterion 1: Distance Between All Pairs of Science Centers According to the Hybrid Model

Performance criterion 2 is calculated. Statistics are given in Figure 16. Minimum distance between closest pair of science centers stays same. Maximum and average distance between all pairs of science centers decreases while *p* increases. Only maximum distance between closest science centers for *p*=5 is different because it shows the existing science center statistics.

To give an example *p*=15 solution is explained here. Solution for minimum distance between all pair of science centers is 132 km which refers to the distance between existing science centers Kocaeli and Bursa. Maximum distance between closest pair of science centers is 445 km which refers to the distance between Aydın and Bursa. Average distance between closest pair of science centers is 313,73 km.

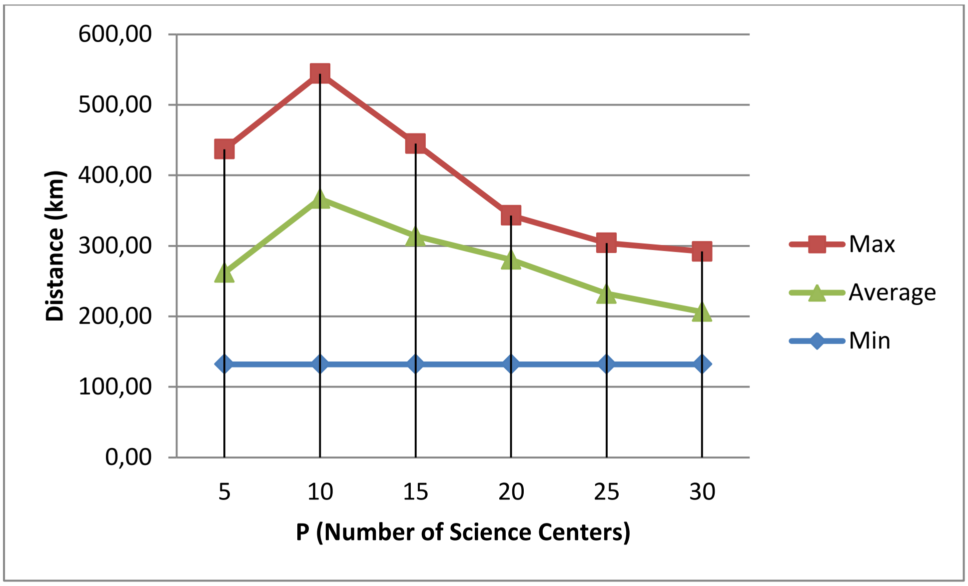


Figure 16: Performance Criterion 2: Distance Between Closest Pair of Science Centers According to the Hybrid Model

Performance criterion 3 is calculated. Statistics are given in Figure 17. According to the statistics minimum total satisfied demand from a science center fluctuates while *p* increases. Maximum total satisfied demand from a science center decreases while *p* increases. But in this pattern, it stays the same for values *p*=20, 25 and 30. It is observed that average total satisfied demand from a science center decreases while p increases.

As an example, *p*=15 solution statistics are explained. Minimum amount of total satisfied demand is 596.614 people. This refers to the science center Artvin satisfies the demand of Rize, Ardahan and its own. Maximum amount of total satisfied demand is 18.871.069 people. This number refers to the existing science center in Kocaeli which satisfies the demand of Bolu, İstanbul, Sakarya, Zonguldak, Yalova, Düzce and its own.

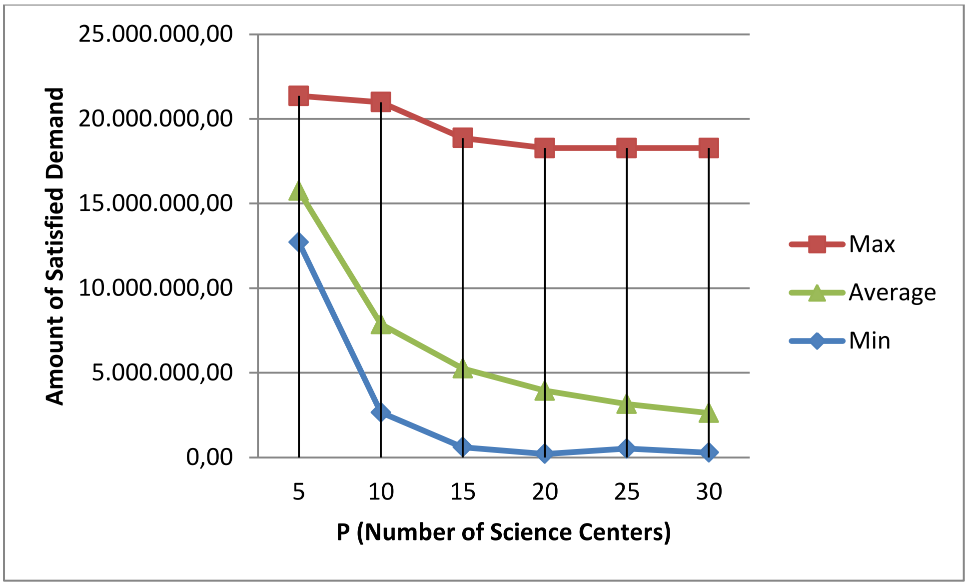


Figure 17: Performance Criterion 3: Amount of Total Satisfied Demand by Each Science Center According to the Hybrid Model

Performance criterion 4 is calculated and statistics are given in Figure 18. According to the solutions, minimum distance between the demand city and existing science centers is 37 km (*p*=5*)*. Minimum distance between the demand city and science centers is 37 km whereas for *p* values of 10, 15 and 20. For *p* values of 25 and 30 it decreases to 35 km. Maximum and average distance between a demand city and a science center decrease while *p* increases. Maximum value of *p*=5 differs from this pattern.

P=15 solution is explained here. Minimum distance between the demand city Sakarya and existing science center Kocaeli is 37 km. Maximum distance between the demand city Antalya and exiting science center Konya is 322 km. On the average people travel 153,38 km to reach science center.

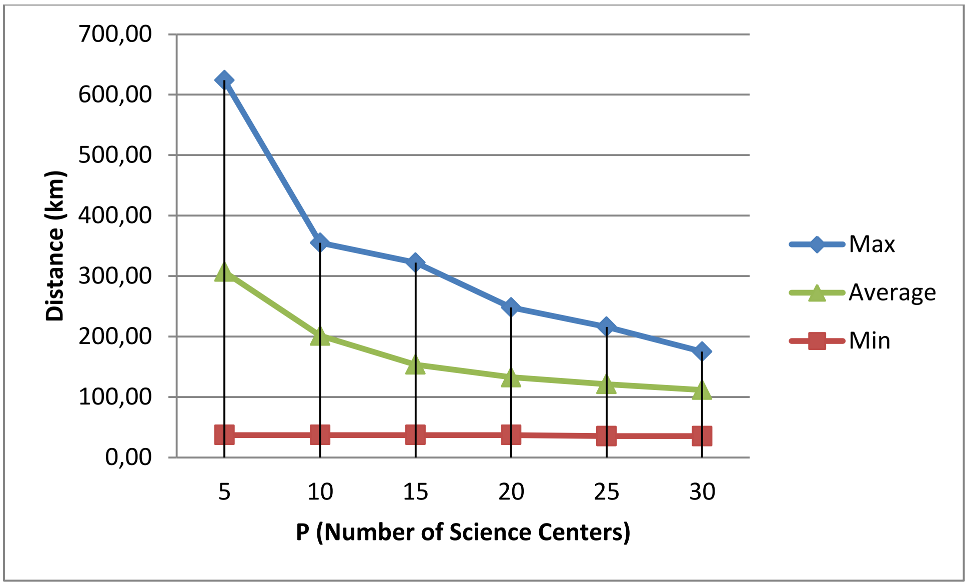
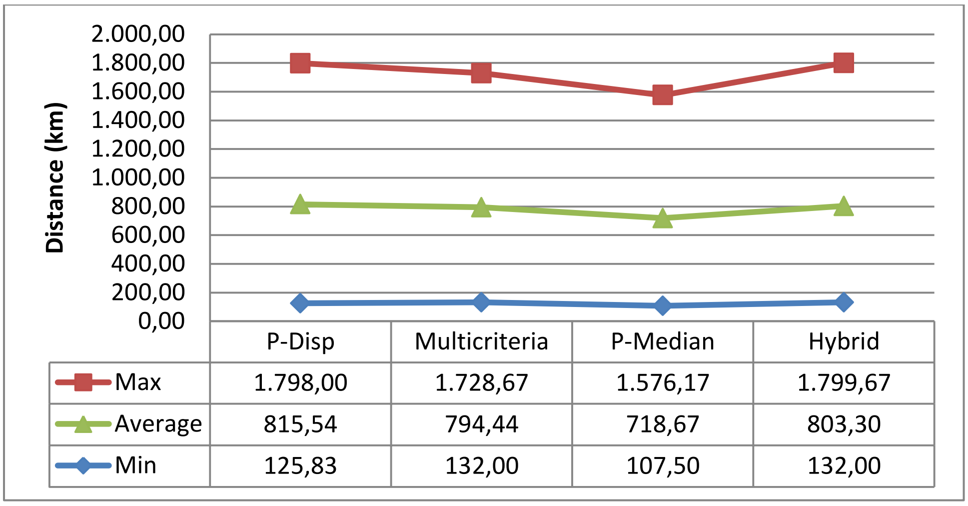


Figure 18: Performance Criterion 4: Distance Between Demand Point *i* and Science Center *j* According to the Hybrid Model

5.6. Comparison of models

P-dispersion, multicriteria approach, *p*-median model and hybrid model solutions are compared with each other in this section. Performance metrics for these models are given in Appendix F. Average of minimum, average of maximum and average of average values for different *p* solutions are compared to each other in this section.

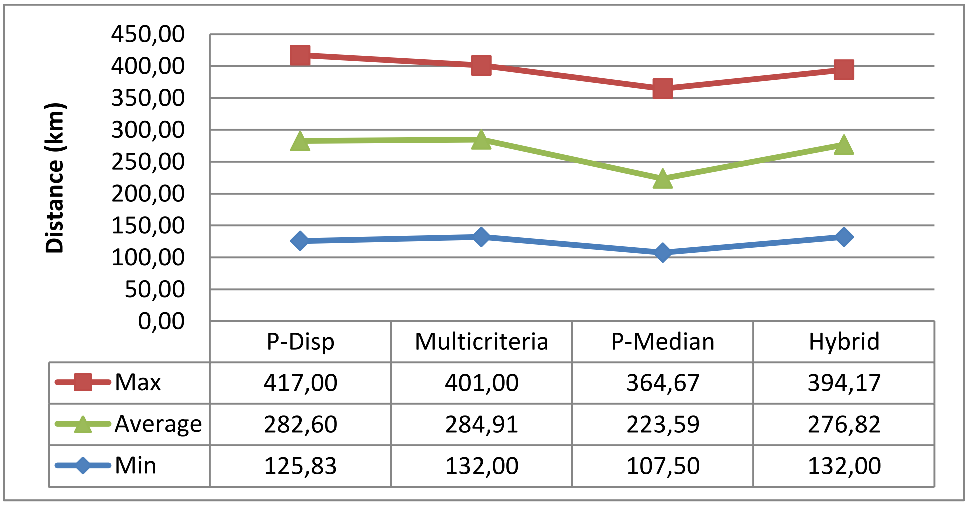
Performance criterion 1 is given for these models in Figure 19 and average values are explained. According to solutions *p*-dispersion model locates science center furthest from each other concerning distances between all science centers. Proposed hybrid model gives the second furthest distance between all science centers on the average. Locating science centers furthest to each other is desired to prevent them serve the same people in common.



	P-Disp	Multicriteria	P-Median	Hybrid
Max	1.798,00	1.728,67	1.576,17	1.799,67
Average	815,54	794,44	718,67	803,30
Min	125,83	132,00	107,50	132,00

Figure 19: Comparison of Performance Criterion 1

Second performance criterion shows the statistics in Figure 20. Multicriteria and *p*-dispersion models give the furthest distance on the average for the distances between the closest pair of science centers Hybrid model gives the third furthest distance values.



	P-Disp	Multicriteria	P-Median	Hybrid
Max	417,00	401,00	364,67	394,17
Average	282,60	284,91	223,59	276,82
Min	125,83	132,00	107,50	132,00

Figure 20: Comparison of Performance Criterion 2

Third performance criterion is given in Figure 21. Demand is considered only in *p*-median and the hybrid model. Because of this reason, statistics are given only for these models. According to solutions average of satisfied demand for each science center in both models are nearly same.

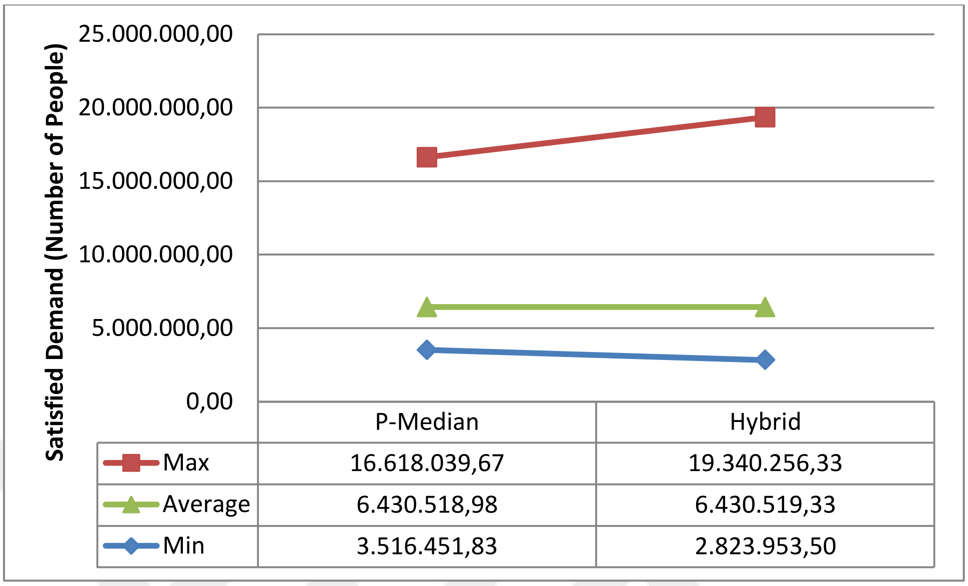


Figure 21: Comparison of Performance Criterion 3

Performance criterion 4 statistics are given in Figure 22. Distance between a demand point and a science center can be calculated only for *p*-median and the hybrid model because only they consider population. Average distance of hybrid model is lower than *p*-median solution. This shows that possible visitors of science centers are closer to the science centers in the hybrid model solution on the average.

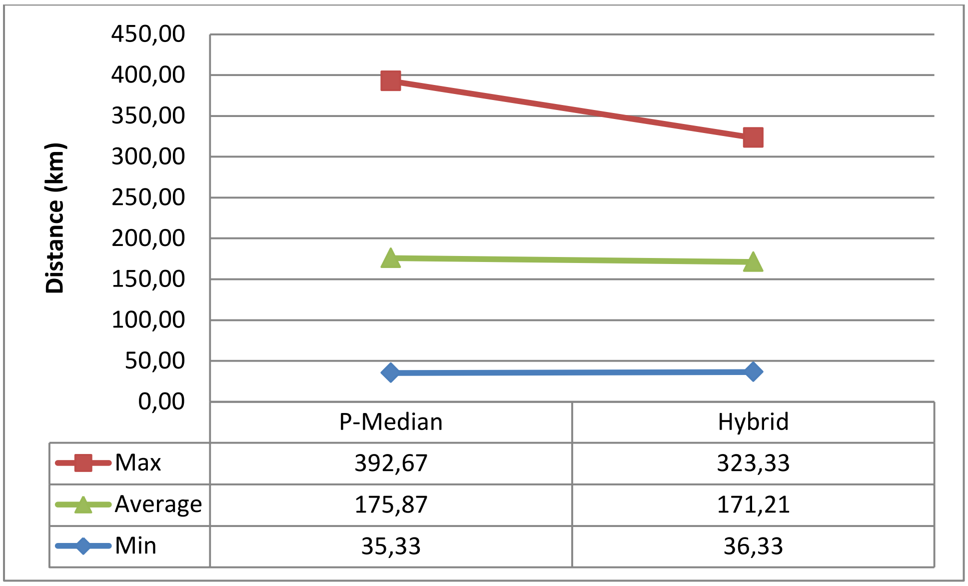


Figure 22: Comparison of Performance Criterion 4

5.7. Hybrid model and existing situation

There are five science centers in Turkey which was opened by the support of TÜBİTAK and local government. In addition to these science centers eight cities have pre-contract with TÜBİTAK to open science centers. Hence, thirteen science centers case (p = 13) can be considered as the existing situation in the near future. Science center location problem and preliminary results were presented to TÜBİTAK experts on 3 August 2016. It was learned that minimum distance between all pairs of science centers is desired to be minimum 150 km. Based on this parameter, hybrid model is solved for p=13 with a minimum separation distance between science centers (D) taken as 150 km. Existing situation is solved according to the hybrid model. Existing science centers and pre-contract signed cities are inserted into the hybrid model as opened science centers. Assignment of cities to these science centers is found to compare solution of hybrid model and existing situation. Objective function values are given in Table 6. It is seen that proposed model gives better solution than existing situation for objective function. Because existing situation's objective function value is %35 greater than proposed hybrid model's objective function value.

Table 6: Compareness of Objective Function Values of Existing Situation and Hybrid Model for *p*=13, *D*=150 km

Hybrid Model Solution	**Objective Funtion Value**
Hybrid model for existing situation	10.300.768.760
Hybrid model for *p* = 13 and *D*=150 km	7.616.872.504

Hybrid model solution for *p*=13 and *D*=150 is compared with the existing situation. Selected cities according to hybrid model are given in the Figure 23 and existing science centers and pre-contract signed cities are given in Figure 24. Selected cities are given in Appendix E. Adana, Antalya and Gaziantep are in common for hybrid model solution and pre-contract signed cities. As it is seen in the Figure 24 some science centers are located very close to each othes (e.g. Tokat and Samsun, Balıkesir and Bursa) in existing situation. Hybrid model allocates science centers further from each other compared to the existing situation.

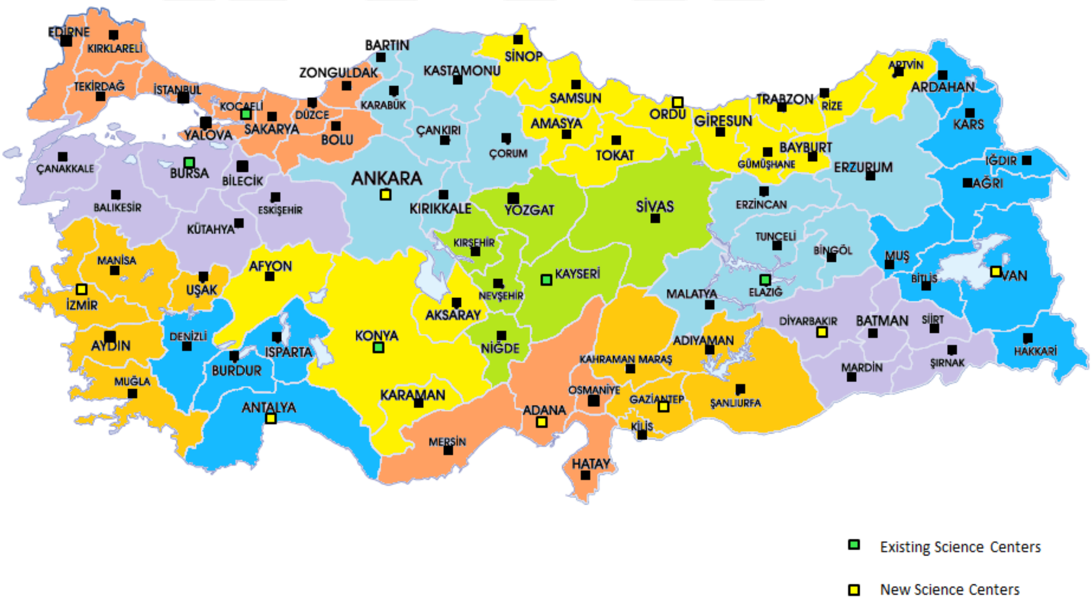


Figure 23: Selected Science Centers According to the Hybrid Model (*D*=150 km)

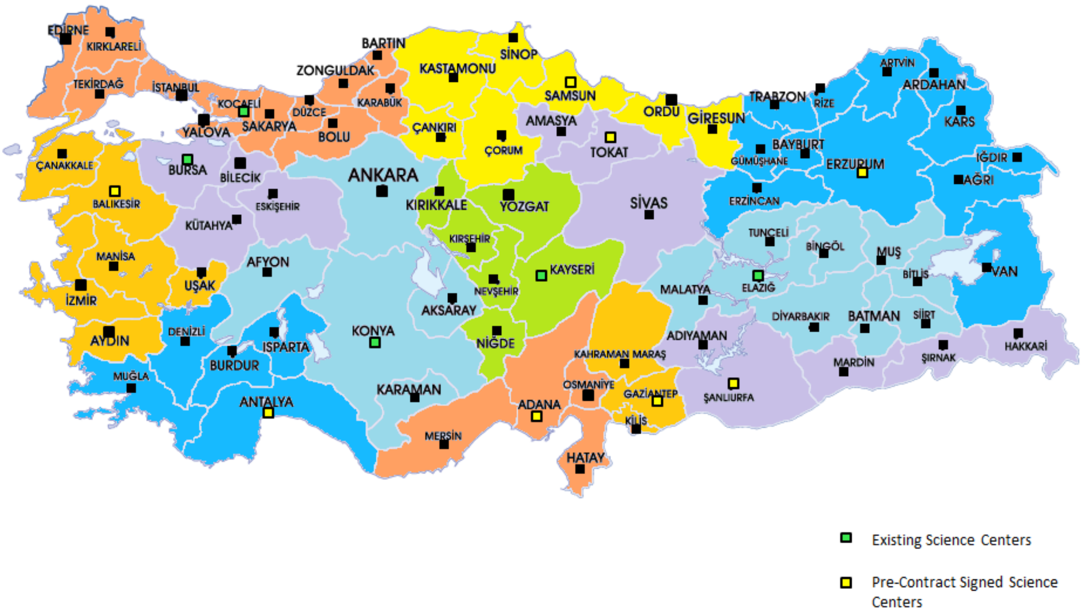
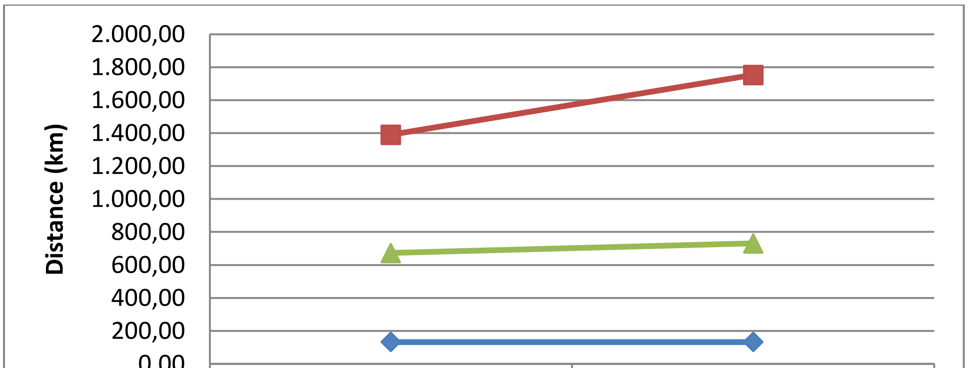


Figure 24: Existing and Pre-contract Signed Science Centers

Performance criteria are compared to each other. Performance criterion 1 is given for these models in Figure 25. Maximum and average distances between all science centers for hybrid model are greater than existing situation. Minimum distances are both same. Proposed hybrid model locates all pairs of science centers further from each other than existing situation.



	Existing Situation	Hybrid Model
Max	1.390,00	1.752,00
Average	672,26	730,42
Min	132,00	132,00

Figure 25: Comparision of Performance Criterion 1 for Hybrid Model and Existing Situation for *P*=13

Performance criterion 2 is given in Figure 26. Maximum and average distances between closest pairs of science centers for hybrid model are greater than existing situation. Minimum distances are both same. Proposed hybrid model locates closest pairs of science centers further from each other than existing situation.

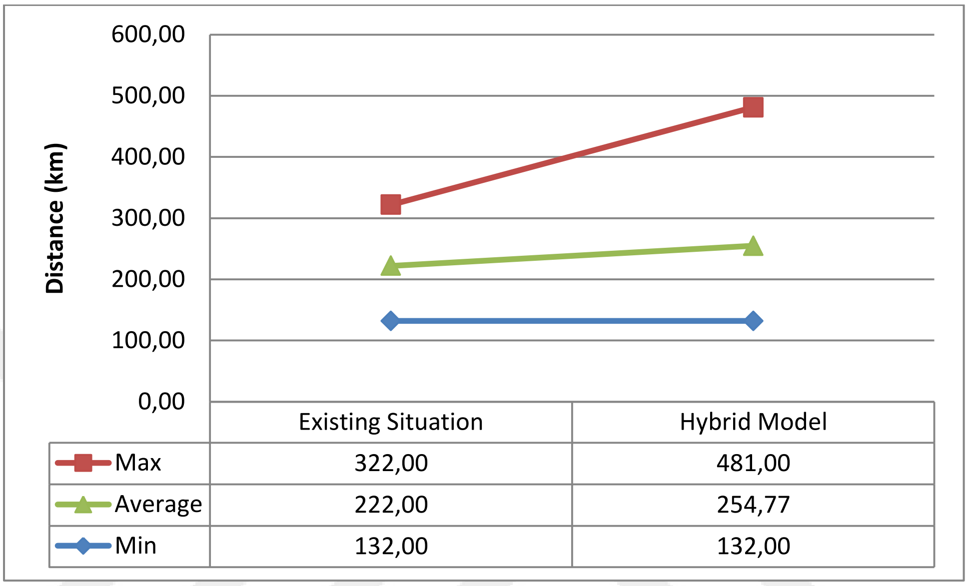


Figure 26: Comparision of Performance Criterion 2 for Hybrid Model and Existing Situation for *P*=13

Performance criterion 3 is given in Figure 27. Maximum satisfied demand is lower for hybrid model than existing situation. That means a science centers serve 20.558.489 people at most in hybrid model. In the existing situation, a science center is required to serve more people than the hybrid model. Minimum satisfied demand for hybrid model solution is greater than existing situation. A science center serves at least 2.685.707 people whereas a science center serves 1.534.774 people in the existing situation. Average satisfied demands are exactly same because population and number of science centers are same for both models.

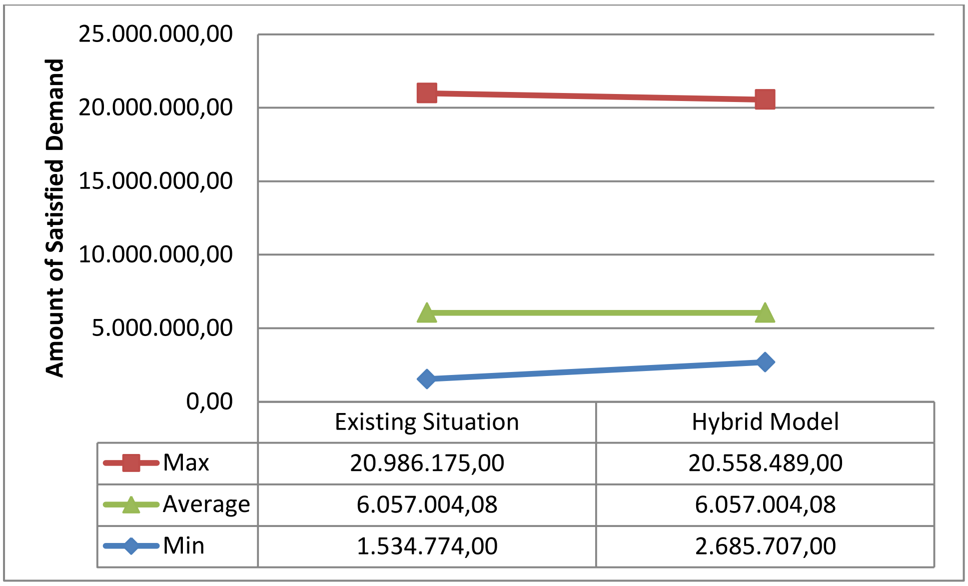


Figure 27: Comparision of Performance Criterion 3 for Hybrid Model and Existing Situation for *P*=13

Performance criterion 4 is given in Figure 28. Maximum, average and minimum distances between all science centers for hybrid model are lower than existing situation. This shows that possible visitors of science centers are closer to the science centers in the hybrid model solution.

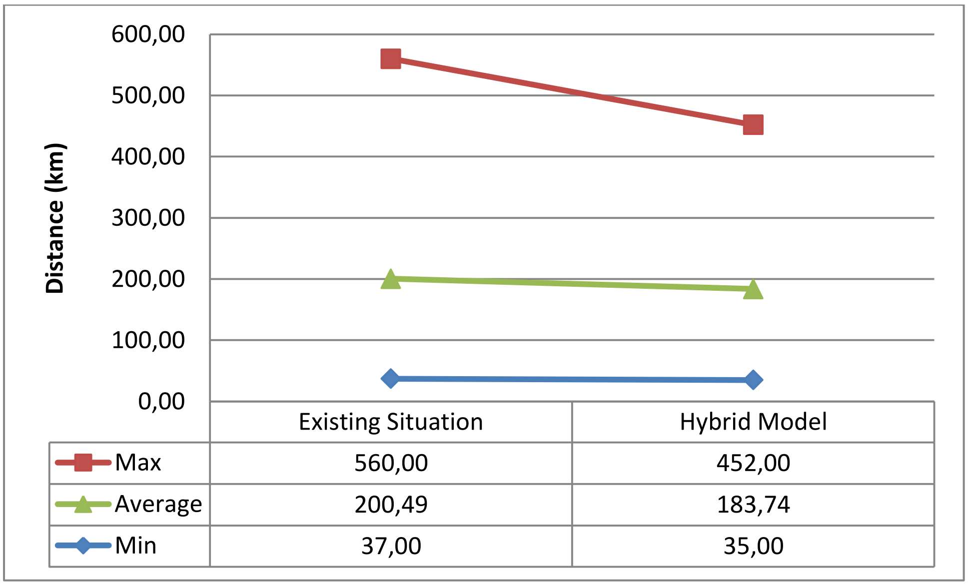


Figure 28: Comparision of Performance Criterion 4 for Hybrid Model and Existing Situation for *P*=13

CHAPTER 6

6. CONCLUSION

Turkish Supreme Council for Science and Technology decided to establish Science Centers with TÜBİTAK's support in all of the metropolitan municipalities by 2016 and in all provinces of Turkey by 2023. In 2016 an additional decision was taken to establish Science Centers in prioritized regional centers except opening them in all provinces because it was seen that the budgets of Science Centers are high and they are attracting visitors from other provinces. Prioritized regional centers were found in this study. The objective of this thesis is to determine the locations of Science Centers in Turkey considering the new criteria defined in the additional decision using integer and mixed integer programming models such as *p*-median, *p*-dispersion and a multicriteria model. A hybrid model was proposed to utilize *p*-median and multicriteria model together. These models locate specific numbers of science centers in Turkey. P-median and hybrid model consider both distance and population criteria. *P*-dispersion, and the multicriteria model consider only distance criterion.

Models were solved for varying *p* (e.g. number of science centers) values of 5, 10, 15, 20, 25 and 30. Selected science center according to the model solutions were given in Appendix A, Appendix B, Appendix C and Appendix D. *P*-median, *p*-dispersion, multicriteria approach and hybrid model solutions did not indicate same cities. There are not common cities for all models for different *p* values.

For each model, common cities are given. In *p*-median model common cities for *p* 10, 15, 20, 25 and 30 solutions are as follows.

- Ankara, İstanbul and İzmir are in common for all solutions.
- Adana, Antalya, Diyarbakır, Gaziantep, Samsun, Trabzon and Van are in common for 4 solutions.

- Aydın, Erzurum, Hatay, Kütahya and Şanlıurfa are in common for 3 solutions.

In p-dispersion model, common cities for *p* 10, 15, 20, 25 and 30 solutions are as follows.

- There is not any city in common for all *p* solutions.
- Hakkari, Muğla and Sinop are in common for 4 solutions.
- Antalya, Artvin, Çankırı, Ordu and Iğdır are in common for 3 solutions.

In multicriteria model, common cities for *p* 10, 15, 20, 25 and 30 solutions are as follows.

- Hakkari is in common for all *p* solutions.
- Muğla and Sinop are in common for 4 solutions.
- Antalya, Hatay, Ordu and Bartın are in common for 3 solutions.

In hybrid model, common cities for *p* 10, 15, 20, 25 and 30 solutions are as follows.

- There is not any city in common for all *p* solutions.
- Samsun is in common for 4 solutions.
- Antalya, Artvin, Hakkari, Hatay, Muğla and Van are in common for 3 solutions.

In this thesis *p*-dispersion and multicriteria models only consider distance between science centers. *P*-median model consider population and distance between cities according to each other but it does not consider distance between science centers. The hybrid model considers distance between cities, population and distance between science centers all together. It locates science centers further distance and visitors of science centers travel less distance than *p*-median model on the average. Because of this reasons hybrid model is proposed. Existing science centers and pre-contract signed city statistics was calculated and they are available in Appendix F. Performance criteria for *p*=15 compared with each other in these statistics. It is obvious that distance between all science centers and closest science centers (performance criteria 1 and 2) is further in hybrid model. And science center visitors travel less distance in hybrid model (performance criteria 4).

Hybrid model is solved for p=13 and minimum separation distance 150 km. Adana, Antalya and Gaziantep are common with the existing situation. Solution of hybrid model is compared with the existing situation. Hybrid model aims to locate science centers by minimizing sum of the demand weighted distance. It is seen that objective function value of existing situation is greater than hybrid model solution for p=13 and D=13. Proposed model gives better solution than existing situation. It is observed that science centers are located further to each other, people travel less distance to reach science centers in the hybrid model.

Science center location problem was investigated in this thesis. This study is the first work on science center location problem. In the future mathematical models might be developed. Mathematical model might be run for cities' population of different age groups because science centers can be prioritized for children and young people. Demands might be changed and solutions will be compared with solution stated in this thesis. Another work might be considering cities' development index as a criterion. Science center location might be determined by considering different type of science centers. These studies and new ideas will be studied.

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APPENDICES

A. P-MEDIAN MODEL RESULT: SCIENCE CENTERS TO OPEN

City Plates	P=5	P=13	P=10	P=15	P=20	P=25	P=30
1		1		1	1	1	1
4							1
6			1	1	1	1	1
7		1		1	1	1	1
9					1	1	1
10		1				1	1
16	1	1	1	1	1	1	1
19							1
20							1
21				1	1	1	1
23	1	1	1	1	1	1	1
25		1			1	1	1
27		1		1	1	1	1
31					1	1	1
33							1
34			1	1	1	1	1
35			1	1	1	1	1
38	1	1	1	1	1	1	1
41	1	1	1	1	1	1	1
42	1	1	1	1	1	1	1
43					1	1	1
52			1				1
55		1		1	1	1	1
56						1	1
58							1
59						1	1
60		1				1	
61				1	1	1	1
63		1			1	1	1
65				1	1	1	1
67							1
78						1	
80			1				

B. *P*-DISPERSION MODEL RESULT: SCIENCE CENTERS TO OPEN

City Plates	P=5	P=13	P=10	P=15	P=20	P=25	P=30
1		1					1
2							1
3						1	
4							1
5							1
6							1
7		1			1	1	1
8				1	1		1
10		1					
13				1	1		
16	1	1	1	1	1	1	1
17						1	
18				1	1	1	
20						1	
22				1	1		
23	1	1	1	1	1	1	1
24						1	
25		1					1
27		1					
29							1
30			1	1	1		1
31					1		1
33						1	
35						1	1
36			1				1
37							1
38	1	1	1	1	1	1	1
39						1	
41	1	1	1	1	1	1	1
42	1	1	1	1	1	1	1
47							1
48			1	1	1		1
49						1	1
52					1	1	1
53						1	
55		1		1			
57			1		1	1	1

58							1
59							1
60		1				1	
61			1				
63		1			1		
64					1		1
65						1	1
67						1	
69				1	1		
73						1	1
74					1		1
75						1	
76				1	1	1	
79				1		1	

C. MULTICRITERIA APPROACH RESULT: SCIENCE CENTERS TO OPEN

P Dispersion Multicriteria (D Excluded) Model							
City Plates	P=5	P=13	P=10	P=15	P=20	P=25	P=30
1		1					
2						1	1
3						1	
4					1		1
5							1
6							1
7		1			1	1	1
8				1			1
9				1			
10		1					
13				1			
16	1	1	1	1	1	1	1
17						1	1
18				1	1		
19						1	
22				1			
23	1	1	1	1	1	1	1
24							1
25		1				1	1
26							
27		1					
30			1	1	1	1	1
31			1		1	1	
33						1	1
35						1	1
36			1				1
38	1	1	1	1	1	1	1
39					1	1	
41	1	1	1	1	1	1	1
42	1	1	1	1	1	1	1
47						1	1
48			1		1	1	1
49							1
52					1	1	1
53						1	

55		1		1			
56					1	1	
57			1		1	1	1
58							1
59							1
60		1					
63		1			1		
64					1		1
65							1
69				1	1		
73							1
74					1	1	1
75					1	1	
76				1		1	
79							1
80				1			

D. HYBRID MODEL RESULT: SCIENCE CENTERS TO OPEN

City Plates	P=5	P=13	P=10	P=15	P=20	P=25	P=30
1		1					1
3						1	1
4					1		1
6						1	1
7		1			1	1	1
8			1	1	1		
9			1	1			
10		1					
13				1			
16	1	1	1	1	1	1	1
17						1	1
18				1	1		
22				1			
23	1	1	1	1	1	1	1
24							1
25		1				1	1
27		1			1		1
28							1
29				1			
30				1	1		1
31			1			1	1
33					1	1	
35						1	1
36							1
37							1
38	1	1	1	1	1	1	1
39					1	1	
40							
41	1	1	1	1	1	1	1
42	1	1	1	1	1	1	1
47							1
48					1	1	1
49						1	1
52					1		
53							1
55		1	1	1		1	1
56					1		

57					1		
59							1
60		1				1	1
61						1	
63		1				1	
64					1		
65			1			1	1
67						1	1
69					1		
72						1	
73							1
74					1		
75						1	
76				1		1	
80				1			

E. HYBRID MODEL (*P*=13, *D*=150 KM) AND EXISTING SITUATION (*P*=13) RESULT: SCIENCE CENTERS TO OPEN

City Plates	Existing Situation (*p*=13)	*p*=13, *D*=150 km
1	1	1
6		1
7	1	1
10	1	
16	1	1
21		1
23	1	1
24		
25	1	
27	1	1
35		1
38	1	1
41	1	1
42	1	1
52		1
55	1	
60	1	
63	1	
65		1

F. MODELS METRICS

Performance criterion 1: *Distance between all pairs of science centers*.

P-dispersion model

	Distance (km)		
P	Min	Max	Average
5	132,00	1128,00	623,00
10	132,00	1772,00	879,51
13	132,00	1390,00	672,26
15	132,00	2040,00	879,35
20	132,00	2040,00	856,52
25	132,00	1866,00	834,61
30	95,00	1942,00	820,27

Multicriteria model

	Distance (km)		
P	Min	Max	Average
5	132,00	1.128,00	623,00
10	132,00	1.772,00	882,47
13	132,00	1390,00	672,26
15	132,00	2.040,00	868,51
20	132,00	2.021,00	852,37
25	132,00	2.021,00	868,04
30	132,00	2.008,00	835,19

P-median model

	Distance (km)		
P	Min	Max	Average
5	132,00	1.128,00	623,00
10	111,00	1.285,00	640,00
13	132,00	1.390,00	672,26
15	111,00	1.752,00	749,00
20	111,00	1.752,00	757,00
25	111,00	1.770,00	774,00
30	69,00	1.770,00	769,00

Hybrid model

	Distance (km)		
P	Min	Max	Average
5	132,00	1.128,00	623,00
10	132,00	1.735,00	831,80
13	132,00	1.390,00	672,26
15	132,00	2.040,00	868,17
20	132,00	2.021,00	834,34
25	132,00	1.866,00	836,54
30	132,00	2.008,00	825,94

Performance criterion 2: *Distance between the closest pairs of science centers*

P-dispersion model

	Distance (km)		
P	Min	Max	Average
5	132,00	437,00	261,80
10	132,00	567,00	378,20
13	132,00	322,00	222,00
15	132,00	544,00	322,40
20	132,00	343,00	291,40
25	132,00	317,00	235,64
30	95,00	294,00	206,13

Multicriteria model

	Distance (km)		
P	Min	Max	Average
5	132,00	437,00	261,80
10	132,00	567,00	393,60
13	132,00	322,00	222,00
15	132,00	445,00	314,53
20	132,00	331,00	282,20
25	132,00	309,00	241,12
30	132,00	317,00	216,20

P-median model

	Distance (km)		
P	Min	Max	Average
5	132,00	437,00	262,00
10	111,00	431,00	276,10
13	132,00	322,00	222,00
15	111,00	370,00	238,80
20	111,00	370,00	209,80
25	111,00	322,00	192,64
30	69,00	258,00	162,20

Hybrid model

	Distance (km)		
P	Min	Max	Average
5	132,00	437,00	261,80
10	132,00	544,00	366,70
13	132,00	322,00	222,00
15	132,00	445,00	313,73
20	132,00	343,00	280,40
25	132,00	304,00	232,00
30	132,00	292,00	206,30

Performance criterion 3: *Amount of satisfied demand from each science center*	
P median	see table below
Hybrid	see table below

P median

Total Satisfied Demand			
P	Min	Max	Average
5	12.700.847,00	21.358.808,00	15.748.210,60
10	3.237.556,00	16.344.854,00	7.874.105,30
13	1.534.774,00	20.986.175,00	6.057.004,00
15	1.700.468,00	16.344.854,00	5.249.403,00
20	1.533.507,00	16.344.854,00	3.937.052,00
25	1.186.688,00	14.657.434,00	3.149.642,00
30	739.645,00	14.657.434,00	2.624.701,00

Hybrid

Total Satisfied Demand			
P	Min	Max	Average
5	12.700.847,00	21.358.808,00	15.748.210,60
10	2.650.011,00	20.986.175,00	7.874.105,30
13	1.534.774,00	20.986.175,00	6.057.004,08
15	596.614,00	18.871.069,00	5.249.403,53
20	204.133,00	18.275.162,00	3.937.052,65
25	513.341,00	18.275.162,00	3.149.642,12
30	278.775,00	18.275.162,00	2.624.701,77

Performance criterion 4: *Distance between demand point i and science center j*

P median

Distance between i and j			
P	**Min**	**Max**	**Average**
5	37,00	624,00	276,00
10	35,00	624,00	224,56
13	37,00	560,00	200,49
15	35,00	365,00	164,85
20	35,00	283,00	146,67
25	35,00	230,00	123,98
30	35,00	230,00	119,16

Hybrid

Distance between i and j			
P	**Min**	**Max**	**Average**
5	37,00	624,00	307,00
10	37,00	355,00	201,45
13	37,00	560,00	200,49
15	37,00	322,00	153,38
20	37,00	248,00	132,59
25	35,00	216,00	121,13
30	35,00	175,00	111,71