QATAR UNIVERSITY

COLLEGE OF ENGINEERING

LOCATION ANALYSIS FOR PRIMARY HEALTHCARE CENTERS IN DOHA CITY USING OPTIMIZATION MODELS WITH SUSTAINABILITY PERSPECTIVE

BY

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ABSTRACT

ALMASHHADNAI, AHMED, MUSTAFA., Masters: June: 2024,

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Title: Location Analysis For Primary Healthcare Centers In Doha City Using Optimization Models With Sustainability Perspective

Supervisor of Thesis: Dr. Kadir, Ertogral.

This thesis employs Mixed Integer Linear Programming (MILP) techniques to optimize the location of healthcare centers with a focus on environmental and social sustainability. The MILP models developed aim to minimize the weighted traveled distance, CO2 emissions from public transport, and patient no-show percentage while maximizing fairness in healthcare service distribution. Through computational experiments and validation against primary healthcare facilities in Qatar, the models recommend opening a minimum of six new centers and allocating patients accordingly. Additionally, a phased plan model is proposed to control budget constraints and resource allocation during implementation. Future research can explore further enhancements to the MILP models by incorporating additional factors influencing location decisions and leveraging advanced optimization techniques. This approach contributes to enhancing healthcare accessibility while addressing environmental and social sustainability concerns.

DEDICATION

To the best of my knowledge, this thesis contains no material previously published or written by another person or institution, except where due reference is made in the text of the thesis. This thesis contains no material which has been accepted for the award of any other degree in any university or other institution.

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CHAPTER 1: INTRODUCTION

Primary healthcare facilities play a pivotal role in ensuring the well-being and health of individuals within a community. These facilities serve as the cornerstone of healthcare systems worldwide, providing essential services that address a wide range of health needs. The importance of primary healthcare lies in its comprehensive approach to healthcare delivery, its focus on prevention and early intervention, its role in reducing health disparities, and its ability to promote community health and resilience.

One of the fundamental aspects of primary healthcare is its emphasis on preventive care and health promotion. By offering services such as vaccinations, screenings, and health education, primary healthcare facilities empower individuals to take control of their health and prevent the onset of diseases. Through early detection and intervention, primary healthcare helps mitigate the progression of illnesses, ultimately reducing the burden on more specialized and costly forms of care. Moreover, primary healthcare plays a crucial role in addressing the diverse healthcare needs of communities. These facilities offer a wide range of services, including routine check-ups, management of chronic conditions, maternal and child health services, and mental health support. By providing accessible and comprehensive care, primary healthcare ensures that individuals receive timely treatment for their health concerns, regardless of their socio-economic status or geographic location.

Primary healthcare facilities serve as the first point of contact for individuals seeking healthcare services. This accessibility is essential in promoting health equity and reducing disparities in healthcare access and outcomes. In many underserved communities, primary healthcare facilities are the only source of healthcare available, making them indispensable in ensuring that everyone has access to essential health services. These facilities often serve as hubs for health promotion activities, community outreach programs, and collaborative initiatives with local organizations. By engaging with communities and addressing their unique health needs, primary healthcare facilities foster a sense of belonging and ownership over health outcomes, leading to healthier and more resilient communities.

The strategic location of healthcare facilities is of paramount importance in ensuring equitable access to healthcare services for all individuals within a community. Utilizing quantitative methods to determine the optimal placement of these facilities can significantly enhance the effectiveness and efficiency of healthcare delivery systems. Quantitative analysis allows policymakers and healthcare planners to make data-driven decisions based on factors such as population density, geographic distribution, demographic characteristics, and healthcare utilization patterns.

One of the primary advantages of employing quantitative methods in healthcare facility location planning is the ability to identify areas with the greatest need for healthcare services. By analyzing population data, including demographic characteristics such as age, income level, and prevalence of chronic diseases, planners can pinpoint underserved communities that require increased access to healthcare. Quantitative methods enable the calculation of various metrics, such as population-to-provider ratios or distance to the nearest healthcare facility, to assess the adequacy of existing healthcare infrastructure and identify gaps in service coverage.

Furthermore, quantitative analysis facilitates the optimization of healthcare facility placement to maximize accessibility and minimize travel distance for patients. Geographic information systems (GIS) and spatial analysis techniques enable planners to model different scenarios and identify the most efficient locations for healthcare facilities based on factors such as population distribution and transportation networks. By strategically locating facilities in areas with high population density or limited access to transportation, healthcare planners can ensure that individuals can easily access essential healthcare services without encountering significant barriers.

Additionally, quantitative methods facilitate the optimization of resource allocation and healthcare delivery workflows. By analyzing healthcare utilization patterns and patient flow, planners can identify areas of overutilization or underutilization of services and adjust facility locations or service offerings accordingly. Quantitative analysis also enables the estimation of future healthcare needs based on population projections and epidemiological trends, allowing for proactive planning and investment in healthcare infrastructure to meet anticipated demand.

This study is intended to

A) Review the current patient allocation for the Primary Healthcare centers to provide a recommendation to the decision maker on how to enhance the utilization of the existing centers by altering the patients allocation by:

   a- minimizing the CO_2 emissions from public transport by minimizing the weighted total distance traveled by the population

   b- Maximizing the Fairness in distributing the healthcare services among residence by minimizing the maximum traveled distance from demand points to the current healthcare facilities.

B) Based on the forecasted population figures up to year 2035, an optimization model is developed to provide a recommendation to the decision maker where to locate the new centers and how to allocate the patient after opening the new centers considering environmental and social sustainable factors. The objective function will be :

   a- Minimizing the CO_2 emissions from public transport by minimizing the weighted total distance traveled by the population.

b- Maximizing the Fairness in distributing the healthcare services among residence by minimizing the maximum traveled distance from demand points to the current healthcare facilities.

c- Maximizing the patient's satisfaction by minimizing the No Show to appointment phenomenon.

C) The model will provide the decision maker with a phase-wise plan to determine when to open each of the new facilities.

1.1 Background

1.1.1 History of Clinics

The history of clinics around the world is closely linked to the development of modern medicine and public health systems. The concept of a clinic as a specialized healthcare facility focused on outpatient care emerged in the 19th century in Europe and North America, as medical knowledge and technology advanced and populations began to grow rapidly (Orgnization, 2003). One of the earliest examples of a clinic was the London Dispensary, founded in 1696 to provide free medical care to the poor. However, it wasn't until the mid-1800s that the idea of a clinic as a specialized healthcare facility really began to take hold (Forum, 2023). In France, for example, the first hospital-based outpatient clinics were established in the mid-1800s as part of the development of the public health system. In the United States, the first modern clinic was the Massachusetts General Hospital Outpatient Department, which opened in 1857.

Over time, clinics became an important part of the healthcare landscape, particularly for underserved populations who may not have had access to hospitals or other healthcare facilities. In the early 20th century, for example, the American Red Cross established a network of rural health clinics to provide basic medical care to people living in remote areas (Qatar M. o.-S., 2018). Similarly, community health centers began to emerge in the 1960s and 1970s as part of the war on poverty in the United States, providing primary care services to low-income and underserved populations. Today, clinics are a common feature of healthcare systems around the world, providing a wide range of medical services to people of all ages and backgrounds. They play a crucial role in promoting public health and ensuring that everyone has access to high-quality healthcare, regardless of their income or social status.

1.1.2 Healthcare in Qatar

Qatar has a modern and well-developed healthcare system that includes a range of health centers and facilities. Health centers in Qatar can be found as follows:

1- Primary Healthcare Centers (PHCCs): These are the first point of contact for many patients in Qatar's healthcare system. There are over 20 PHCs located throughout the country, providing a wide range of primary care services, including routine check-ups, vaccinations, and minor procedures.

2- Hamad General Hospitals: These are the main hospitals in Qatar's healthcare system, providing a range of specialized medical services, including emergency care, surgery, and intensive care.

3- Specialized Hospitals: Qatar also has a number of specialized hospitals that focus on specific medical areas, such as the National Center for Cancer Care and Research (NCCCR), the Rumailah Hospital for Women and Children, and the Heart Hospital.

4- Ambulatory Care Centers (ACCs): These are specialized outpatient facilities that provide a range of diagnostic and treatment services, such as radiology, laboratory testing, and physiotherapy.

5- Mental Health Centers: Qatar has several mental health centers, including the Psychiatry Department at Hamad Medical Corporation, which offers a range of services for patients with mental health disorders.

6- Private Wellness Centers: Qatar also has several private wellness centers, such as Aspetar, which is a sports medicine hospital that provides specialized services for athletes, and the Al-Ahli Hospital Wellness Center, which offers a range of health and wellness services, including nutrition counselling and fitness classes.

As the Primary Healthcare Centers are the first point of contact for locals and residence, State of Qatar Government has deployed 26 centers around Qatar to serve them, out of which nine centers are established in Doha city as the population in Doha is much denser than other districts (Qatar M. o.-S., 2018).

1.1.3 The Use of Primary HealthCare Facilities

According to the ministry of Health in Qatar, the Primary healthcare facilities in Qatar serve as the cornerstone of the country's healthcare system, playing a crucial role in promoting community health, preventing diseases, and providing accessible and comprehensive healthcare services to the population (Primary Health care Corporation, 2017). Here are some key uses and functions of primary healthcare facilities in Qatar:

1- Preventive Care: Primary healthcare facilities in Qatar focus on preventive measures such as immunizations, health screenings, and health education programs to promote healthy behaviors and prevent the onset of diseases.

2- Health Promotion: These facilities engage in health promotion activities to raise awareness about healthy lifestyle choices, disease prevention, and early detection of health problems through community outreach programs and educational campaigns.

3- Chronic Disease Management: Primary healthcare facilities play a vital role in managing chronic conditions such as diabetes, hypertension, and asthma through regular monitoring, medication management, and lifestyle counseling.
4- Routine Medical Care: They provide routine medical care for common health concerns, such as colds, flu, minor injuries, and infections, ensuring timely access to healthcare services for individuals and families.
5- Maternal and Child Health Services: Primary healthcare facilities offer maternal and child health services, including prenatal care, postnatal care, well-child visits, and vaccinations, to promote the health and well-being of mothers and children.
6- Management of Acute Conditions: In addition to preventive and routine care, these facilities also manage acute conditions that require immediate attention, such as injuries, infections, and acute illnesses, providing timely diagnosis and treatment.
7- Referral and Coordination: Primary healthcare facilities serve as the first point of contact for individuals seeking healthcare services. They assess patients' needs, provide appropriate treatment or referrals to specialists or hospitals when necessary, and ensure coordination of care across different healthcare providers.
8- Community Engagement: Primary healthcare facilities engage with the community to understand their healthcare needs, gather feedback, and tailor services to meet the unique requirements of diverse population groups, including expatriates and marginalized communities.

1.2 Scope

This thesis aims to develop a comprehensive model for the optimal location of healthcare centers with a focus on integrating sustainable aspects. The model will consider environmental, social, and economic sustainability factors to guide the placement of healthcare facilities in a manner that maximizes accessibility, minimizes environmental impact, and promotes community well-being.

Through a thorough review of existing literature and methodologies related to healthcare facility location and sustainable development, this research will identify key variables and criteria that influence the selection of optimal locations for healthcare centers.

The proposed model will employ advanced analytical techniques, such as geographic information systems (GIS), multi-criteria decision analysis (MCDA), and optimization algorithms, to analyze spatial data, prioritize potential locations, and generate optimal solutions that balance sustainability objectives with healthcare service requirements.

Furthermore, this thesis will conduct a case study focusing on the primary healthcare centers in Qatar. By applying the developed model to the context of Qatar's healthcare system, the study will assess the current distribution of primary healthcare facilities, evaluate their sustainability performance, and identify opportunities for improvement.

The findings of this research endeavor will contribute to the advancement of knowledge in the fields of healthcare facility planning, sustainable development, and spatial analysis. Moreover, the insights gained from the case study in Qatar will provide actionable recommendations for policymakers, urban planners, and healthcare stakeholders to enhance the sustainability and effectiveness of primary healthcare services in the country.

Through this interdisciplinary approach, this thesis seeks to address the critical need for integrating sustainability principles into healthcare facility location planning, thereby fostering healthier, more resilient, and environmentally responsible communities.

1.3 Methodology

The methodology employed in this thesis encompasses several key steps. Beginning with a comprehensive review of existing literature and methodologies, relevant variables and criteria influencing optimal healthcare center locations, including population density, transportation accessibility, environmental factors, socioeconomic indicators, and healthcare service demand, will be identified. Subsequently, spatial data pertaining to these variables will be collected from various sources. Leveraging advanced analytical techniques such as GIS, MCDA, and optimization algorithms, a model integrating sustainability aspects into healthcare facility location planning will be developed. This model will undergo scenario analysis to assess different criteria weights and parameters' impacts, ensuring robustness. A case study focusing on primary healthcare centers in Qatar will then be implemented to map current distribution, evaluate sustainability performance, and identify improvement areas. Through validation and calibration using real data, the model's accuracy and reliability will be assured. Finally, analysis and interpretation of case study results will yield insights and recommendations, documented comprehensively in the thesis report, aiming to inform policy, planning, and decision-making processes in Qatar's healthcare system.

1.4 Report Organization

The report is organized into six main chapters, each serving a distinct purpose in the exploration and analysis of healthcare facility location optimization with a focus on sustainability factors.

Chapter 1, the Introduction, provides an overview of the thesis objectives, significance, and outlines the structure of the report.

Chapter 2, the Literature Review, delves into existing literature pertaining to public needs and satisfaction in healthcare, sustainability factors including environmental and economic impacts, and previous studies in healthcare facility optimization.

Chapter 3, Problem Setting and Description, delineates the current and projected data concerning healthcare facility placement, setting the stage for subsequent analysis.

Chapter 4, Problem Formulation, is divided into subsections addressing the mathematical formulation of key aspects such as allocating current registered patients, locating new health centers for future expansion, and strategies for improving sustainability.

Chapter 5, Multi-period Facility Location, presents the model to phase the establishment of the new healthcare centers based on the results collected from the developed model.

Finally, Chapter 6, Conclusion and Future Research, synthesizes the findings, draws conclusions, and suggests avenues for future research in the realm of healthcare facility location optimization and sustainability. Through this structured organization, the report aims to provide a comprehensive exploration of the subject matter while offering insights and recommendations for practice and further investigation.

CHAPTER 2: LITERATURE REVIEW

The literature that is pertinent to the current thesis is analyzed in this section. The papers are arranged according to how they examined the issue of healthcare facility placement. The flaws in the literature that currently exist are then noted, and it is described how this study fits within these gaps.

2.1 Mathematical Approaches in Addressing Location Problems

Academic research into the placement of health-care facilities began in the early 1960s (Alimoahmmadi, 2015). Hakimi introduced healthcare network design into the location literature by representing the difficulty of locating police stations and hospitals as a network. There has been a lot of research on healthcare network architecture since then. Daskin and Dean (2004) and Afshari and Peng (2014), listed review papers, focused on healthcare location problem. Furthermore, they presented comprehensive guidelines with a review to assist readers in selecting and implementing strategies for healthcare facility site (Amir Ahmadi-Javid, 2017). Their findings provide a current and comprehensive overview of strategies and criteria for locating healthcare facilities.

The first published study using a mathematical model to identify primary healthcare (PHC) facilities that optimize cancer screening program participation was conducted by Verter and Lapierre in 2002. The model contains case studies on Georgia, USA, and Montreal, Canada, and outlines a minimum work load limit for institutions to maintain accreditation. Travel time or distance is utilized as a stand-in for accessibility, while decreases in accessibility are represented by partial coverage. But the approach simply takes into account the time or distance traveled by clients; it ignores the impact of facility services, including line congestion.

In another study, Zhang et al. (2009) included congestion into Verter and Lapierre (2002)'s participation modeling using an M/M/1 queue technique. Their nonlinear programming model aimed to maximize the level of interaction of a PHC network. The estimated cumulative time is used as a stand-in for PHC facility accessibility. This time includes waiting, travel, and service time. The presumption that each client will travel a minimum distance or require a minimum amount of time is replaced with the minimum projected total time for visiting the facility. Expected total time is chosen as the main element impacting the likelihood of participation rather than total trip time or distance. To determine the ideal locations for PHC facilities, they developed four unique heuristic solution techniques since their buildup model was non-linear.

A mixed-integer programming model was introduced by Davari et al. (2016) for the purpose of developing PHC networks while taking equity and budgetary restrictions into account. To solve their suggested model, they created a skewed variable neighborhood search algorithm.

Researchers have employed many techniques to address the issue of healthcare facility placement. Mathematical treatments of the problem have been found in the literature, including modeling with geographical concerns. Multi-objective optimization Zhang et al. (2016); Beheshtifar and Alimoahmadi (2015); Harper et al. (2005); a Mixed Integer Non-Linear Programming approach Radman and Eshghi (2018); a Network-based covering location problem (Net-CLP) approach Ye and Kim (2016); and a Multi-Objective Mixed Integer Programming location model Dogan et al. (2020). Facility location problems have considered a variety of objective functions. In general, facility location problems are classified into several categories such as (Single facility vs multi facility location, Discrete vs continuous facility location, Minimize / maximize problems, etc.) According to Farahani et al. (2019), the most often employed study objectives in this area include minimizing the travel distance, optimizing service level, minimizing waiting time, maximizing coverage, minimizing transportation expenses, and avoiding installation adjacent to hazardous sites. The maximum availability service facility site problem in an urban area was examined by Muffak and Arslan, taking into account both fixed and mobile demand. They created a Benders decomposition method with several acceleration approaches and offered a formulation for mixed-integer linear programming (Muffak and Arslan, 2023).

An overview of the objective functions considered in the healthcare industry's facility location problems is shown in Table 1.

Table 1. Summary Of Objective Functions and Solution Approaches In Related Healthcare Facility Location Problems (Delen, 2023)

SN	Study	Approach	Objective function(s)
1	(Beheshtifar and Alimoahmmadi 2015)	Hybrid GA and GIS analysis	Minimize transportation costs Minimize unequal access to healthcare center Maximize site land-use compatibility Minimize land purchase and establishment costs
2	(Mestre et al. 2015)	Stochastic optimization	Minimize the expected travel time Minimize the expected cost
3	(Guerriero et al. 2016)	Exact optimization	Maximize the covered demand
4	(Ye and Kim 2016)	Exact optimization	Minimize the total number of facilities.
5	(Zhang et al. 2016)	Multi-objective GA	Maximize population accessibility Minimize inequity of accessibility Minimize the people outside a travel distance Minimize the cost of building a new facility
6	(Radman and Eshghi 2018)	GA-based heuristic	Minimize total distance traveled by patients Minimize deviation in arrival rates
7	(Dogan et al. 2020)	Exact optimization	Minimize deviation in possible participation Minimize deviation in waiting time Minimize deviation in budget

SN	Study	Approach	Objective function(s)
8	(Muffak and Arslan 2023)	Benders decomposition	Minimize deviation in budget Maximum availability service
9	Babak Aslani, Meysam Rabiee, Mona Jabbari3 and Dursun Delen 2023	multi-objective mixed-integer linear programming	Minimize total travel distance, Maximizing local covering & effectiveness and overlap functions

2.2 Public Needs and Satisfaction

The location of healthcare facilities plays a crucial role in ensuring accessibility and satisfaction among the public. Understanding the needs and preferences of the community is vital for effective healthcare facility planning and development (Amir Ahmadi-Javid, 2017). This literature review examines studies focusing on public needs and satisfaction regarding healthcare facility location, exploring factors influencing decision-making and strategies to address community requirements.

Accessibility to healthcare facilities significantly impacts public satisfaction. A study by (Kihal-Talantikite, 2018) found that proximity to healthcare services was a primary determinant of satisfaction among residents. Communities prefer facilities located within reasonable distances, minimizing travel time and costs. Additionally, access to public transportation enhances facility reachability, particularly for underserved populations (Dulin, 2016).

Demographic characteristics influence public needs and preferences for healthcare facility location. Research by (Khan, 2019) demonstrated variations in location preferences based on age, income, and health status. For instance, older adults prioritize facilities with geriatric services, while low-income populations emphasize proximity and affordability. Understanding these demographic nuances is essential for equitable facility distribution (Khan, 2019).

Incorporating community input in healthcare facility location decisions fosters satisfaction and acceptance. Public participation enhances transparency and ensures that facilities align with community needs (Reeder, 2018). Studies suggest that engaging stakeholders through surveys, focus groups, and town hall meetings facilitates collaborative decision-making, leading to better outcomes and increased public satisfaction (Gupta A. C., 2017).

Public satisfaction is closely linked to the quality of healthcare services provided. Research by (Aung, 2020) highlighted the importance of considering service quality alongside location. Factors such as physician expertise, technological resources, and patient-centered care influence facility preferences. Public perception of service quality affects utilization rates and overall satisfaction levels (Aung, 2020).

2.3 Sustainability Factors

The sustainable location of healthcare facilities is crucial for ensuring equitable access, minimizing environmental impact, and optimizing resource utilization. This literature review synthesizes research on sustainability factors influencing healthcare facility location decisions, including environmental considerations, community impact, and economic viability.

Sustainability in healthcare facility location encompasses minimizing environmental impact through responsible site selection and design. Research by (Cheng, 2019) emphasizes the importance of considering ecological factors such as land use, air quality, and biodiversity conservation. Green building practices, energy efficiency, and renewable energy integration contribute to reducing carbon footprint and promoting environmental sustainability (Cheng, 2019).

Transportation infrastructure and accessibility play a pivotal role in sustainable facility location planning. Studies highlight the need to prioritize locations with efficient public transit options, pedestrian-friendly infrastructure, and proximity to major transportation hubs (Baik et al., 2020). Accessible facilities reduce reliance on private vehicles, decrease traffic congestion, and enhance overall community well-being (Baik, 2020).

Sustainable healthcare facility location considers the social and economic impact on surrounding communities. Research by Brown et al. (2018) underscores the importance of community engagement and stakeholder involvement in decision-making processes. Addressing community needs, promoting social equity, and fostering partnerships with local organizations contribute to sustainable facility development and positive community outcomes (Brown, 2018).

The resilience of healthcare facilities to natural disasters and climate change impacts is integral to sustainability. Studies emphasize the significance of locating facilities in areas with reduced vulnerability to hazards such as floods, earthquakes, and extreme weather events (Zhang 2021). Incorporating resilient design principles, disaster preparedness strategies, and emergency response protocols ensures continuous healthcare service delivery and enhances community resilience (Zhang L. L., 2021).

Sustainable healthcare facility location involves balancing environmental and social considerations with economic viability. Research by Lee et al. (2020) explores cost-effectiveness analyses and financial feasibility studies in facility location decision-making. Factors such as land acquisition costs, construction expenses, operational efficiency, and revenue generation potential influence the economic sustainability of healthcare facilities (Lee, 2020).

Healthcare facility location decisions have significant environmental implications, affecting factors such as land use, air quality, energy consumption, and overall ecological sustainability. This literature review synthesizes existing research on the environmental impact of healthcare facility location, exploring strategies for mitigating adverse effects and promoting sustainability.

The location of healthcare facilities influences land use patterns and urban development. Research by Yu et al. (2019) highlights the role of facility location in urban sprawl, which can lead to habitat loss, fragmentation, and decreased biodiversity. Strategic planning that prioritizes infill development, brownfield redevelopment, and compact facility designs can minimize land consumption and mitigate sprawl-related environmental impacts (Yu, 2019).

Healthcare facilities contribute to air pollution through vehicular traffic, energy consumption, and medical waste generation. Studies emphasize the importance of locating facilities away from air quality-sensitive areas such as residential neighborhoods and sensitive ecosystems (Gupta et al., 2018). Green building standards, energy-efficient design, and adoption of renewable energy sources reduce emissions and improve air quality around healthcare facilities (Gupta A. M., 2018).

The energy demand of healthcare facilities significantly impacts environmental sustainability. Research by Hong et al. (2020) underscores the need for location decisions that prioritize energy efficiency and renewable energy integration. Proximity to public transit, adoption of green transportation strategies, and implementation of energy-saving technologies contribute to reducing energy consumption and greenhouse gas emissions associated with facility operation (Hong, 2020).

Healthcare facilities generate substantial amounts of hazardous and non-hazardous waste, posing environmental challenges. Sustainable location planning involves considering waste management infrastructure, recycling facilities, and environmentally friendly disposal methods (Marufu et al., 2019). Locating facilities in areas with robust waste management systems and promoting waste reduction, reuse, and recycling practices contribute to resource conservation and environmental protection (Marufu, 2019).

2.4 Literature Gaps

After reviewing and analyzing the publications that address the Healthcare Facilities location problem the following gaps were identified. First, papers listed above uses a range of criteria concerned mainly about economic aspect and rarely involve the social and environmental ones. To address this issue, this study consider economic, Social and environment sustainability criteria organized in a hierarchy to assist the decision-makers in taking the decision.

Second, majority of techniques have been applied to small-scale problems in the literature. Population projections and the placement of healthcare facilities are complicated topics, though. The developed model should be robust for large-scale problems if the demand and capacity projections are accurate.

Moving forward, Sustainable site selection for healthcare facilities involves strategically locating them with considerations for social justice and environmental stewardship. This entails choosing sites that minimize negative environmental impacts, reduce carbon footprint, and protect natural ecosystems while also promoting community health and accessibility.

By opting for sustainable site selection, healthcare facilities can actively contribute to environmental preservation and public health improvement. For instance, by minimizing the distance patients need to travel to access healthcare services, air and water pollution from transportation can be reduced. Additionally, strategically locating facilities away from environmentally sensitive areas can help safeguard air and water quality, mitigating pollution and its adverse health effects.

This study is intended to optimize locating the healthcare facilities considering the fairness in distributing the health services among populations and in environmentally friendly manner.

CHAPTER 3: PROBLEM SETTING AND DESCRIPTION

3.1 Current State Problem Setting

According to the Planning and Statistics Authority, Qatar has experienced a significant population growth over the past few decades. The population has increased from around 500,000 in the early 1990s to an estimated 3 million in 2023 (authority, 2020). This growth has been driven by several factors, including a high level of immigration, a relatively low mortality rate, and a declining but still relatively high fertility rate.

Qatar in the past decades made significant investments in its healthcare system which has helped to improve health outcomes and increase life expectancy. Therefore, the life expectancy in Qatar was estimated to be around 80 years. This is relatively high compared to the global average life expectancy (Qatar P. a., 2020).

Figure 1. Qatar Municipalities Map

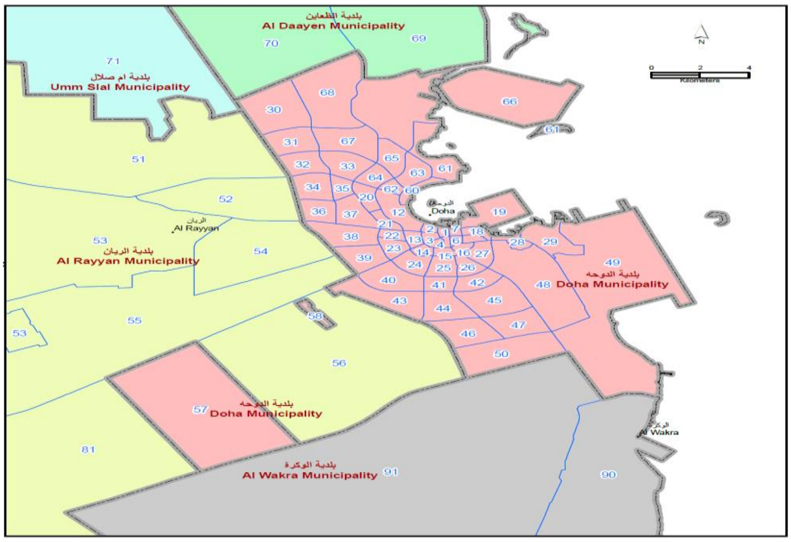

Figure 2. Doha City Zones

The population density in Qatar is 244 people per sq.km, calculated on a total land area of 11,610 sq.KM. However, population are not equally distributed around the country as 40% of population are living in the city of Doha which contribute only around 2% of the state of Qatar area. The Qatar municipality map and Doha city with its zones are given in Figure 1 and 2, respectively.

As this study will be focused on the primary healthcare centers established by the State of Qatar serving the population living in Doha, the following is the population distribution within 68 Doha zones.

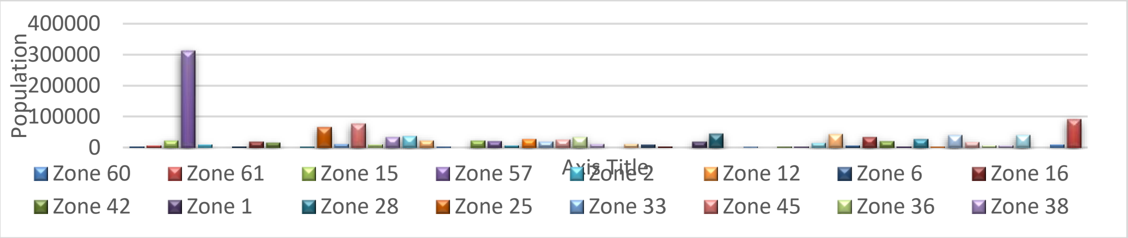

Figure 3. Current Doha Population by Zones (2020 Census)

Serving the above listed areas, the following primary healthcare centers are established. The table shows their Daily capacity in terms of number of patient visits:

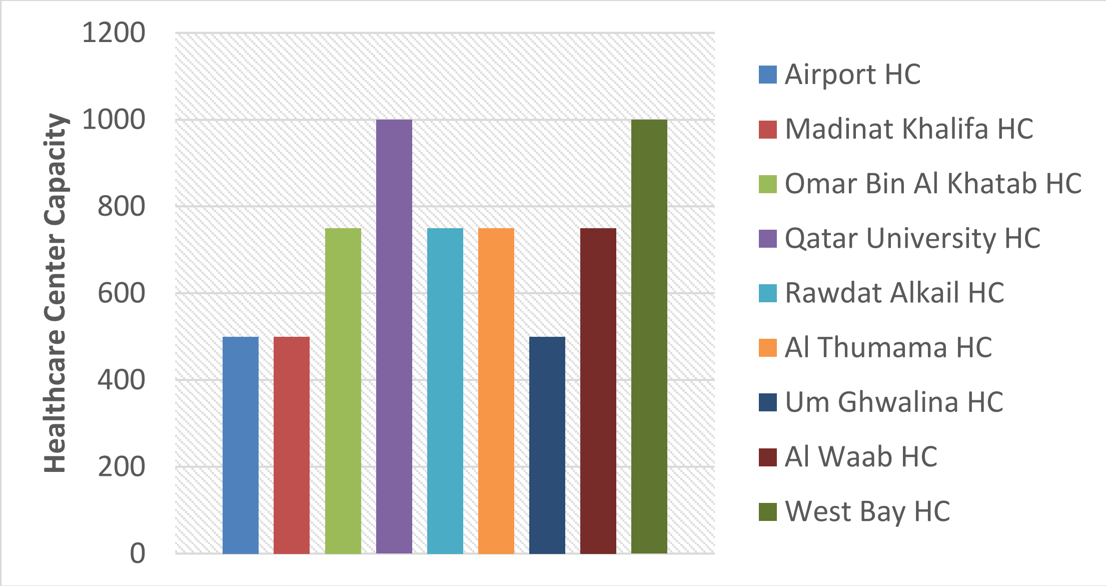

Figure 4. Primary Healthcare Centers Capacity in Doha

Doha is the Capital of State of Qatar with a rapid growth in population. According to the Planning and Statistics Authority 1,028,032 people are living in Doha as of May 2023. This figure is expected to increase by 22.5% at the end of 2035 as forecasted by the same Authority . The centers of the zones (yellow pins), and the current health centers (red points) are shown in Figure 5.

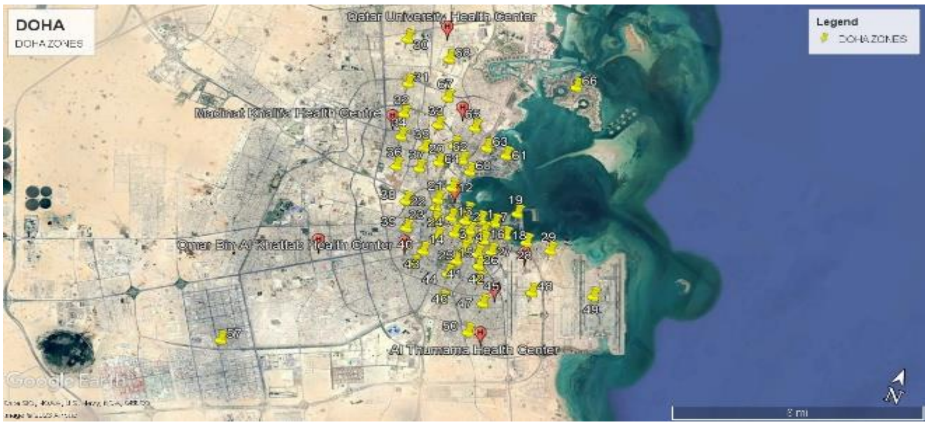

Figure 5. Health Centers and Demand Points Location Map

3.2 Future State Data

Population inflation in Qatar over the next 10 years is anticipated to be substantial, driven by various factors such as sustained economic growth, continued investment in infrastructure and development projects, and ongoing influx of expatriate workers (authority, 2020). With Qatar's ambitious plans for diversification and expansion across sectors such as energy, transportation, and healthcare, the demand for labor is expected to rise, leading to an increase in migrant workers and their families. Based on the available data, the population inflation will be as follows:

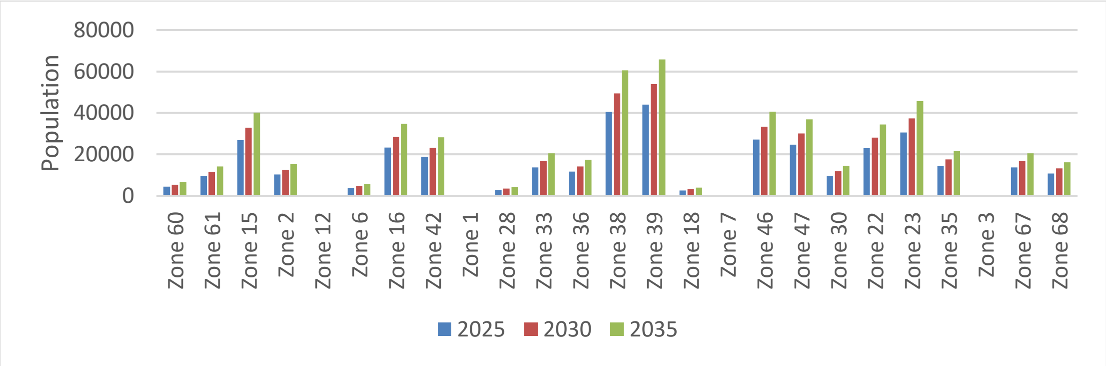

Figure 6. Predicted Doha Population by Zone (1 out of 3)

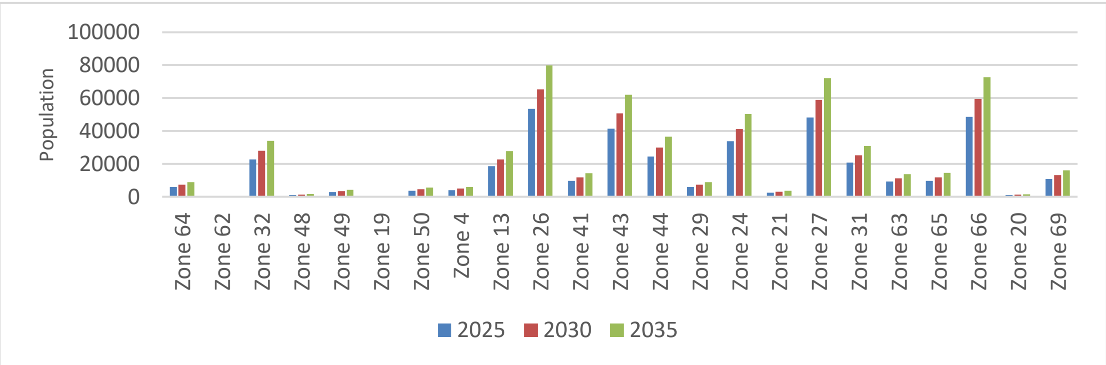

Figure 7. Predicted Doha Population by Zone (2 out of 3)

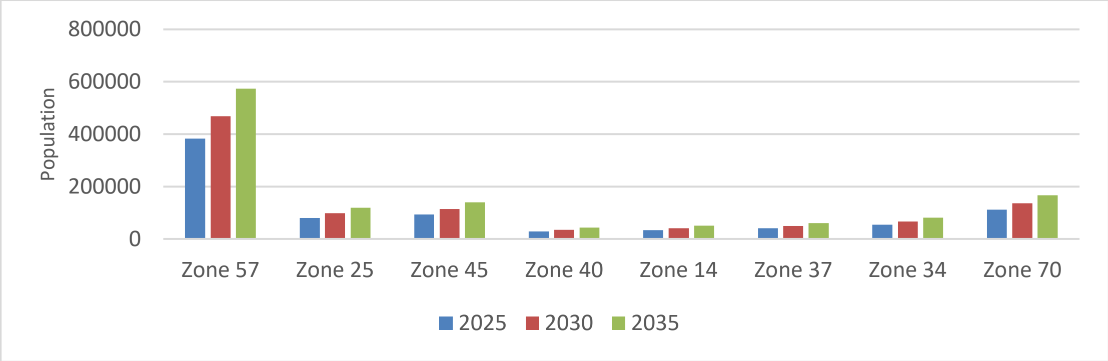

Figure 8. Predicted Doha Population by Zone (3 out of 3)

Based on the 2015 and 2020 censes conducted by the Planning and Statistics Authority which reflects a 22.5% population growth every five years, a yearly population data were generated to be used in the multi period planning model.

CHAPTER 4: PROBLEM FORMULATION

In this chapter, we delve into the formulation of the problem at hand, laying the groundwork for the subsequent analysis. Rather than simply presenting collected data, it's imperative to elucidate the underlying framework guiding our approach.

The decision to employ a specific formulation stem from a comprehensive understanding of the intricacies involved in patient allocation within primary healthcare settings. Our approach is rooted in the need for a mathematical model that not only captures the current state of patient allocation but also offers insights into optimizing resource utilization and enhancing overall efficiency.

Before delving into the details of the collected data, it's paramount to elucidate the rationale behind our chosen methodology. By establishing a robust problem formulation framework, we aim to address key challenges such as optimizing patient flow, mitigating the impact of no-show appointments, and maximizing healthcare center utilization.

Thus, this chapter serves as a foundational cornerstone, delineating our approach to problem formulation and setting the stage for a comprehensive analysis of the collected data. Through a meticulous examination of the underlying principles guiding our methodology, we aim to provide clarity and coherence in addressing the complexities of patient allocation in the primary healthcare context.

4.1 Review of the Current Condition

According to the primary healthcare corporation annual statistical report, the patient allocation strategy was as follows (Primary Health care Corporation, 2017) (Primary Healthcare Corpration, 2018) (Primary Health care Corporation, 2019) (Primary Health care Corporation, 2020) (Primary Health care Corporation, 2021):

Table 2. Current State of Healthcare centers with Total Number of Visits

Year	Number of opened Centers across Qatar	Number of opened Centers across Doha	Total Number of Registered Patients within Doha	Total Number of Visits for the centers within Doha
2017	23	7	452,978	1,357,687
2018	27	9	514,408	1,502,600
2019	27	9	563,518	1,278,005
2020	27	9	625,134	1,262,616
2021	27	9	673,658	2,411,647

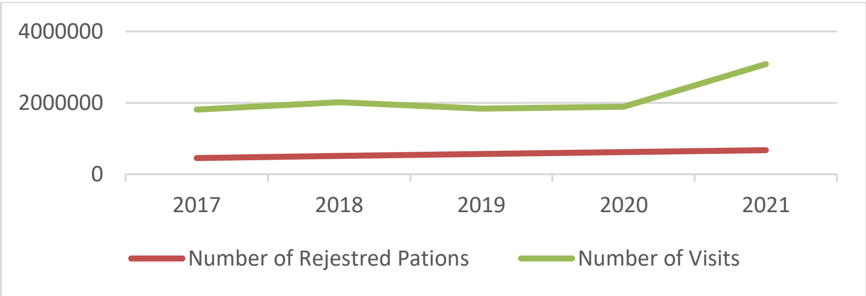

Figure 9. Number of Registered Patients And Visits in Doha for The Period of 2017 to 2021

Based on the above facts, the number of registered patients is equal to 48.6% from the total population recorded for the same year and the average number of visits per registered patients equal to 3.57.

4.2 Current Allocation Evaluation

The published data does not reflect zone wise allocation process by the primary healthcare authority, utilizing GIS technology the distance data was collected from each zone in Doha (56) to each healthcare center open (9) in the year of 2020, the average distance is equal to 13.03 km. that resulted to 16,451,886.5 km as a total traveled distance by public for the same year.

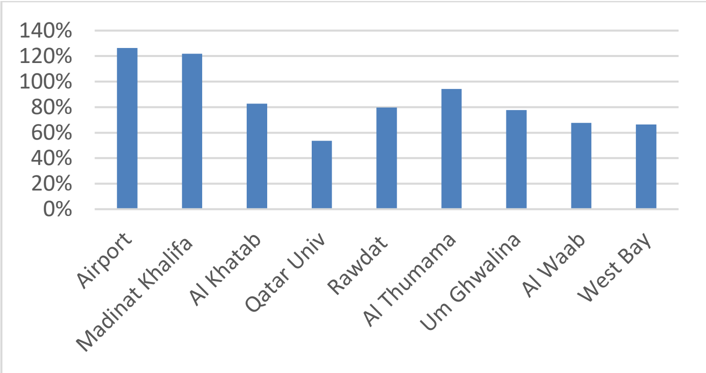

Figure 10. Current Utilization Percentage for the Open Healthcare Centres in 2020

The graph above reflects the utilization rate for each center as published by authority. Which shows clearly that some of the centers were overloaded beyond its capacity and some others are less than 50% utilized.

4.3 Optimizing the Current Allocation Considering the Current Available Centers

4.3.1 P-Median Model

As the purpose of this study is to provide the authority a decision-making tool considering sustainable aspects which is more environmentally friendly, an optimization model was developed to allocate the patient with the current available healthcare centers and demand. The objective of this model is to minimize the total travel distance to reduce CO_2 emissions by public transport.

The model has the following variables:

K: Set of candidates (or open) locations for the healthcare centers. (K = 1,2,3,..,87). first nine locations are currents open locations and the remaining locations are the center of zones as the candidate locations for new facilities)

I: Set of zones in Doha city. (I = 1,2,3,..,78)

The following data was used to build the model;

w_i : Population per each zone i.

C_{pk} : Health centers capacity for the health center at location k (open or to be opened)

d_{ik} : Distances from zone i to health center at location k.

u_{max} : Maximum utilization limit

u_{min} : Minimum utilization limit

4.3.1.1 Decision Variables

Decision variables of the model are;

$$y_k = \begin{cases} 1, \text{if helath center k is selected} \\ 0, \text{otherwise} \end{cases}$$

$$X_{ik} = \begin{cases} 1, \text{if the demand point i is assigned to the Helath center k} \\ 0, otherwise \end{cases}$$

4.3.1.2 Mathematical Model

Mathematical model of the problem based on p-median formulation is as follows;

$$Min\ Z = \sum_{i=1}^{|I|} \sum_{k=1}^{|K|} w_i d_{ik} X_{ik}$$

Subject to

$$\sum_{k=1}^{|K|} X_{ik} = 1 \qquad \forall\ i \in I \qquad [1]$$

$$\sum_{i=1}^{|I|} X_{ik} \leq y_k \qquad \forall\ k \in K \qquad [2]$$

$$3.57 \sum_{i=1}^{|I|} w_i X_{ik} \leq cp_k y_k \qquad \forall\ k \in K \qquad [3]$$

$$3.57 \sum_{i=1}^{|I|} w_i X_{ik} \leq u\_\max\ cp_k y_k \qquad \forall\ k \in K \qquad [4]$$

$$3.57 \sum_{i=1}^{|I|} w_i X_{ik} \geq u\_\min\ cp_k y_k \qquad \forall\ k \in K \qquad [5]$$

$$y\ = 1 \qquad \forall\ k \in \{1,2,..,9\} \qquad [6]$$

$$y_k \in \{0,1\}, X_{ik} \in \{0,1\} \qquad \forall\ k \in K, \forall\ i \in I \qquad [7]$$

The objective function is defined as the minimization of the total travelled distance by the population to reach the healthcare centers. Constrain set [1] assures that each zone is assigned to one health center. Constraint set [2] restricts that the zone is assigned only to an open center. Constraint set [3] restricts the assignment of patients not to exceed annual capacity of open health centers. Constraints [4] and [5] restricts the upper and lower utilization limit. Constraint [6] makes sure that current healthcare centers are fixed as open. While constraint [7] is binary restriction.

4.3.1.3 Results

An optimization software program, IBM ILOG CPLEX Optimization Studio 22.1.1, was used to develop, implement, and test the MILP models that were covered in this chapter and other earlier chapters. Results are presented on the effectiveness of MIP-based heuristics and optimality-based model solution.

Based on the above model, the total travel distance has been optimized to an overall of 10,044,366.6 kilometer with a reduction of 38.95% from the current allocation strategy implemented by the authority. The utilization percentage has been also kept within the range of 40 – 90%.

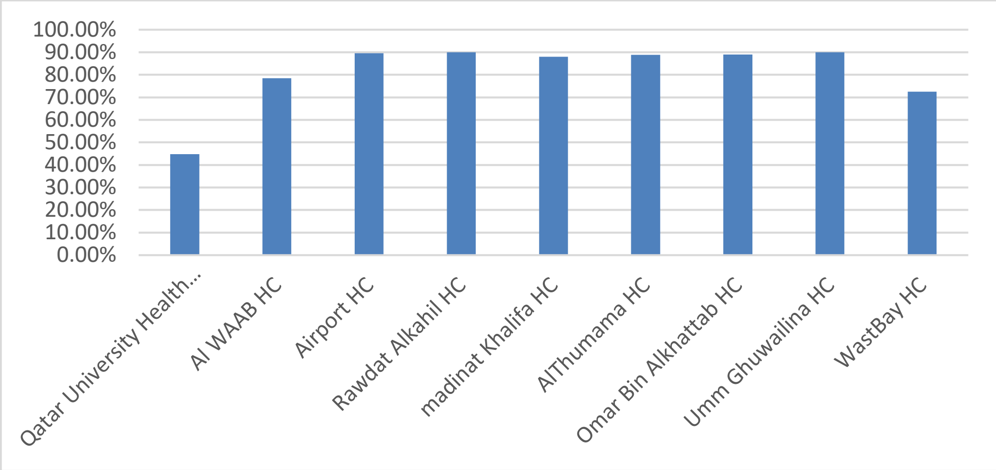

Figure 11. Utilization Percentage After Optimizing the Current Demand

Table 3. Zones Allocation Based on Current Available Healthcare Centres

Healthcare Center	Number of Zones Assigned	Population	HealthCare Center Capacity
Qatar University HC	6	53841	120000
Al WAAB HC	3	94126.2	120000
Airport HC	7	161233	180000
Rawdat Alkahil HC	18	215974	240000
madinat Khalifa HC	11	158364.4	180000
AlThumama HC	6	159902	180000
Omar Bin Alkhattab HC	5	106775.9	120000
Umm Ghuwailina HC	11	161998.5	180000
WastBay HC	11	173869	240000

4.3.2 P-Center Model

As the purpose of this study is to provide the authority a decision making tool considering sustainable aspects, an optimization model was developed to allocate the patient with the current available healthcare centers and demand. The objective of this model is to minimize the maximum travel distance so that we both reduce CO2 emissions generated by the transportation of the customers and ensure the fairness in distributing the healthcare services among the residences.

The same variable mentioned in the P-median model of section 4.3.1 are used here as well.

4.3.2.1 Decision Variables

Decision variables of the model are;

$$y_k = \begin{cases} 1, \text{if helath center k is selected} \\ 0, otherwise \end{cases}$$

$$X_{ik} = \begin{cases} 1, \text{if the demand point i is assigned to the Helath center k} \\ 0, otherwise \end{cases}$$

$$Z = maximum\ distance\ from\ zones\ to\ allocated\ healthcare\ center$$

4.3.2.2 Mathematical Model

Mathematical model of the problem based on p-median formulation is as follows;

$$Min\ Z$$

Subject to

$$\sum_{k=1}^{|K|} d_{ik} X_{ik} \leq \mathrm{Z} \qquad \forall\, i \in I \qquad [1]$$

$$\sum_{k=1}^{|K|} X_{ik} = 1 \qquad \forall\, i \in I \qquad [2]$$

$$\sum_{i=1}^{|I|} X_{ik} \leq y_k \qquad \forall\, k \in K \qquad [3]$$

$$3.57 \sum_{i=1}^{|I|} w_i X_{ik} \leq cp_k y_k \qquad \forall\, k \in K \qquad [4]$$

$$3.57 \sum_{i=1}^{|I|} w_i X_{ik} \leq u\_\mathrm{max}\; cp_k y_k \qquad \forall\, k \in K \qquad [5]$$

$$3.57 \sum_{i=1}^{|I|} w_i X_{ik} \geq u\_\mathrm{min}\; cp_k y_k \qquad \forall\, k \in K \qquad [6]$$

$$y_k \ = 1 \qquad \forall\, k \in \{1,2,..,9\} \qquad [7]$$

$$y_k \in \{0,1\}, X_{ik} \in \{0,1\} \qquad \forall\, k \in K, \forall\, i \in I \qquad [8]$$

P-Center is used here to ensure the fairness in distributing the healthcare facility to all public, The objective function is defined as to minimize the maximum travelled distance by the population to reach the healthcare centers. Constraint set [2] assures that each zone is assigned to one health center. Constraint set [3] restricts that the zone is assigned only to an open center. Constraint set [4] restricts the assignment of patients not to exceed annual capacity of open health centers. Constraint set [5] and [6] restricts the upper and lower utilization limit. Constraint [7] makes sure that current healthcare centers are fixed as open. While constraint [8] is the binary restrictions on the dectition variables.

4.3.2.3 Results

Based on the above model, the maximum traveled distance has been optimized to 17.5 kilometer compared to 32.5 kilometer considered in the current allocation strategy implemented by the public authority which means 46.1% improvement.

4.4 Optimize the Allocation Considering the Future Centers to be Open

Studying the next ten years of population inflation will give the decision maker the opportunity to plan where to open the new centers keeping in mind the sustainability factors and the patient satisfaction in terms of reachability and accessibility.

Determining the future demand was based on the census conducted by the Planning and Statistics Authority in Qatar in 2015 & 2020, which reflect a 22% increase of population is expected over the period of five years. Appendix I reflects spread of a uniformity distributed percentage of population inflation on a yearly basis.

It should be noted that to give the optimizer the flexibility to allocate the patients located at highly populated zones to health centers, sub-zones were created (for example, Zone 57 has been divided into 10 subzones 57A-57J, as the population in zone 57 alone is 1,098,139). However, the distance has been considered the same for all sub-zones as the geographical area of the zone is quite small.

4.4.1 Locating The New Health Centers for Future Expansion by Minimizing the Total Travel Distance (Environmental Sustainability, Model 1)

An optimization model was developed to decide where to open the new healthcare centers considering the population growth in 2035 (10 years forecast) also to re-allocate the patient considering the current and future healthcare centers to be opened. The objective of this model is to minimize the total travel distance in order to reduce CO2 emissions by public transport.

As described in section 4.3.1 (P-Median model), the same parameters, decision variables, objective function and constraints are utilized with one additional constrain to restricts the number of opened healthcare centers

$$\sum_{k=1}^{|K|} y_k \leq \text{P} \qquad [8]$$

4.4.1.3 Results

After running the model, it turned out that six additional healthcare centers needs to be open at least to satisfy the population growth of the next 10 years within the restriction of maintaining the same service level (within the allowable center utilization limits). Table #4 and graphs below reflect the total weighted travel distance and the average utilization percentage in case of opening six to nine additional healthcare centers

Table 4. P-Median Model Result Z1, The Total Weighted Travel Distance and the Average Utilization Percentage

Number of additional healthcare Centers	Total Weighted Traveled Distance (KM)	Average Utilization %
6	8,131,122.55	87.98%
7	6,916,820.87	82.11%
8	5,830,768.10	77.88%
9	4,927,986.97	73.42%

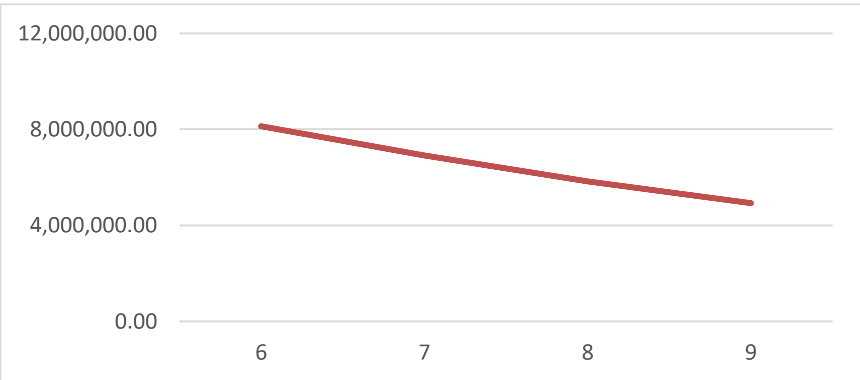

Figure 12. Weighted Travel Distance Vs Number of Healthcare Centres (Z1)

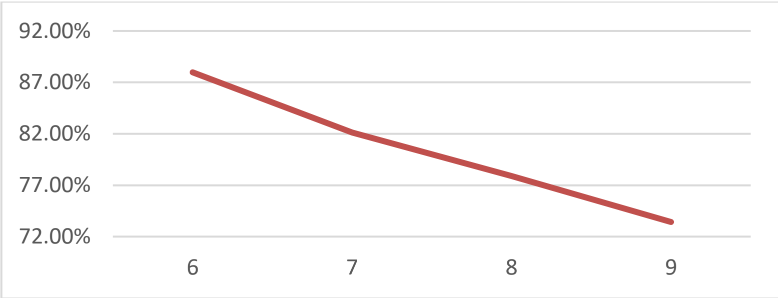

Figure 13. Average Utilization Percentage vs number of new healthcare centers (Z1)

4.4.2 Locating the New Health Centers for Future Expansion by Maximizing the Fairness in Healthcare Provision to All Society (Socially Sustainable) (Z2)

This optimization model was developed to locate the new healthcare centers and to allocate the patient to the current and new healthcare centers based on future expected demand. The objective of this model is to minimize the maximum travel distance and thereby indirectly reduce CO2 emissions generated by the transportation od the public. Minimizing maximum distance will ensure the fairness in distributing the healthcare services among the residents and hence the solution will be more socially sustainable.

As described in section 4.3.2.2 (P-Center model), the same parameters, decision variables, objective function and constraints are utilized with one additional constrain to restricts the number of opened healthcare centers

$$\sum_{k=1}^{|K|} y_k \leq \text{P} \qquad [9]$$

4.4.2.3 Results

After running the model, to satisfy the population growth of the next 10 years six additional healthcare centers are needed to be open as minimum requirement (within the allowable center utilization limits).

Table #5 and figure 17 and 18, reflect the maximum travel distance and the average utilization percentage in case of opening six to nine additional healthcare centers

Table 5. P-Center Model Result Z2, The Maximum Travel Distance and the Average Utilization Percentage

Number of additional healthcare Centers	Maximum Traveled Distance (KM)	Average Utilization %
6	8	88.83%
7	7.8	82.32%
8	7.8	77.29%
9	7.8	73.32%

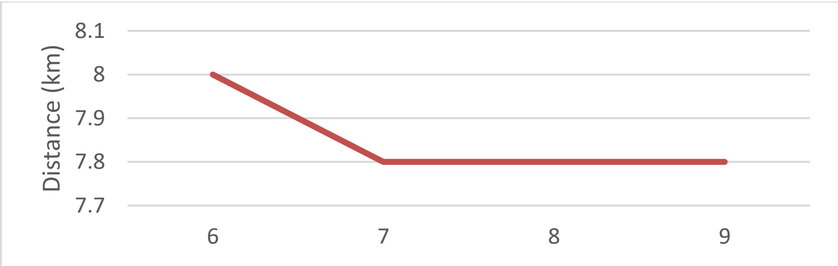

Figure 14. Maximum Travel Distance Vs Number of New Healthcare Centres (Z2)

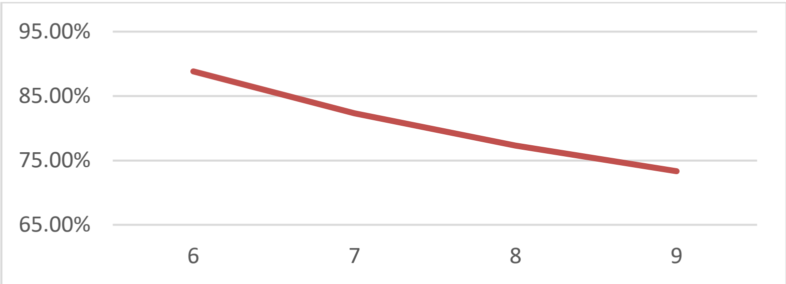

Figure 15. Average Utilization Percentage Vs Number of New Healthcare Centres (Z2)

4.4.3 Locating the New Healthcare Centers For Future Expansion by Minimizing the Patients No Show Due to Long Queuing (Socially Sustainable) (Z3)

Data provided by the primary healthcare cooperation in Qatar for the past 5 years reflected a significant no show phenomenon for scheduled appointments when the assigned healthcare center is over utilized. The table below represents the percentage of patients no show for the centers across Doha.

Table 6. Patients No Show Percentage

SN.	Healthcare Center	No Show %				
		2017	2018	2019	2020	2021
1	Airport HC	36%	28%	12%	18%	37%
2	Madinat Khalifa HC	37%	21%	21%	12%	34%
3	Omar Bin Al Khatab HC	41%	24%	33%	37%	35%
4	Qatar University HC		17%	28%	12%	38%
5	Rawdat Alkahil HC	21%	42%	30%	37%	37%
6	Al Thumama HC	25%	20%	20%	17%	28%
7	Um Ghwalina HC	18%	19%	17%	18%	49%
8	Al Waab HC		16%	26%	17%	40%
9	West Bay HC	44%	42%	60%	10%	30%

To evaluate the relation hypothesis, liner regression was conducted for the data collected from the primary healthcare cooperation.

The following hypothesis are tested

H0	There is a linear relation between the utilization and the no show
H1	There is no linear relation between the utilization and the no show

Table 7. Utilization Vs No Show Linear Regression Result

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.184732	0.184732	15.39178	0.000310042
Residual	43	0.516086	0.012002		
Total	44	0.700818			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	1.128885583	0.413198	2.732069	0.009094
X Variable 1	5.513306293	1.405296	3.923236	0.00031

As P Value is less than 0.05, we fail to reject the null hypothesis. We obtained following linear regression model.

$$Y = 5.513X - 1.129$$

Where Y present the predicted Variable (No Show Percentage)

And X present the dependent variable (Utilization Percentage)

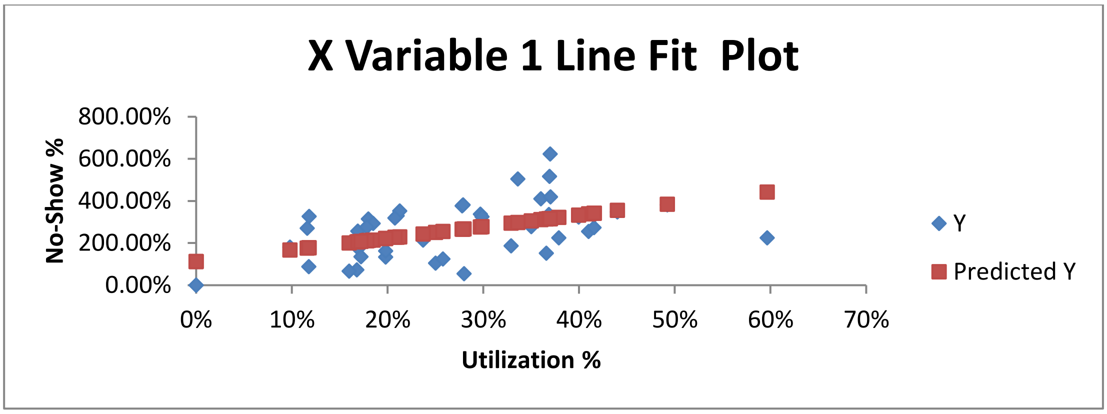

Figure 16. Predicted Value Line Fit Plot

To minimize the no show phenomenon, the following optimization model developed

4.4.3.1 Decision Variables

Decision variables of the model are;

$$y_k = \begin{cases} 1, \text{if helath center k is opened} \\ 0, \mathit{otherwise} \end{cases}$$

$$X_{ik} = \begin{cases} 1, \text{if the demand point i is assigned to the Helath center k} \\ 0, \mathit{otherwise} \end{cases}$$

$u_k = 0 \leq u_k \leq 1$ where u_k is the utilization percentage

4.4.3.2 Mathematical Model

Mathematical model of the problem based on p-median formulation is as follows;

$$min\ Z = \sum_{k=1}^{|K|} (5.513u_k - 1.129y_k)$$

Subject to

$$\sum_{k=1}^{|K|} X_{ik} = 1 \qquad \forall\, i \in I \qquad [1]$$

$$\sum_{i=1}^{|I|} X_{ik} \leq y_k \qquad \forall\, k \in K \qquad [2]$$

$$\sum_{k=1}^{|K|} y_k \leq \mathrm{P} \qquad for\, \forall\, k \in \mathrm{P} \qquad [3]$$

$$3.57 \sum_{i=1}^{|I|} w_i X_{ik} \leq cp_k y_k \qquad \forall\, k \in K \qquad [4]$$

$$3.57 \sum_{i=1}^{|I|} w_i X_{ik} \leq u\_\mathrm{max}\; cp_k y_k \qquad \forall\, k \in K \qquad [5]$$

$$3.57 \sum_{i=1}^{|I|} w_i X_{ik} \geq u\_\mathrm{min}\; cp_k y_k \qquad \forall\, k \in K \qquad [6]$$

$$y_k \;= 1 \qquad \forall\, k \in \{1,2,..,9\} \qquad [7]$$

$$Y_k \in \{0,1\}, X_{ik} \in \{0,1\} \qquad \forall\, k \in K, \forall\, i \in I \qquad [8]$$

4.4.3.3 Results

After running the model, in order to satisfy the population growth of the next 10 years, it turns out that six additional healthcare centers are needed to be open as minimum requirement (within the allowable center utilization limits).

Table #8, figure 17 and 18, reflect the total no show percentage across healthcare centers, and the average utilization percentage in case of opening six to nine additional healthcare centers

Table 8. Z3 Result, Accumulative No Show And The Average Utilization

Number of additional healthcare Centers	Total No show %	Average Utilization %
6	56.25%	87.98%
7	52.79%	80.31%
8	51.65%	75.58%
9	50.52%	71.38%

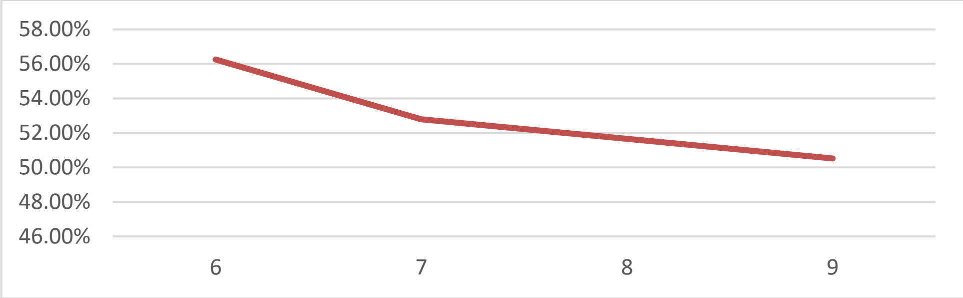

Figure 17. No Show % Vs Number of new Healthcare Centres (Z3)

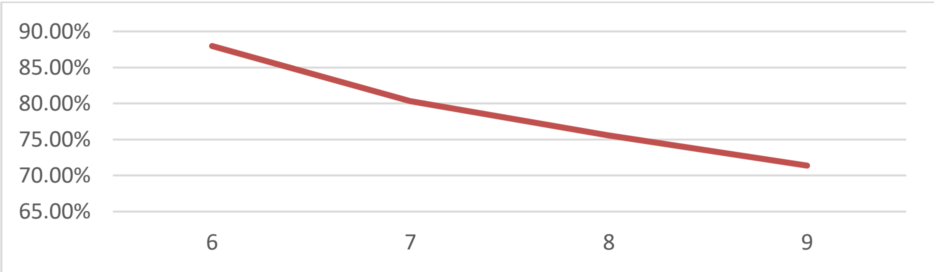

Figure 18. Average Utilization Percentage Vs Number of new Healthcare Centres (Z3)

4.5 Integrated Model

In our developed models, we have established three primary objectives aimed at optimizing the allocation of healthcare resources and enhancing patient access. Firstly, we aim to minimize the weighted traveled distance, ensuring efficient utilization of transportation resources and reducing the overall burden on patients. Secondly, we strive to minimize the maximum travel distance, ensuring equitable access to healthcare services across the population. Lastly, we seek to minimize the patient no-show percentage for scheduled appointments, thereby enhancing appointment adherence and resource utilization. To facilitate the decision-making regarding the number of centers to open and patient allocation strategies with a multi objective perspective, we have constructed an integrated model with a hierarchical prioritization. This model assigns highest priority to minimizing the weighted traveled distance, reflecting its critical importance in optimizing resource allocation. Priority two is assigned to minimizing the patient no-show percentage, acknowledging the significance of appointment adherence in healthcare delivery. Lastly, priority three is attributed to minimizing the maximum travel distance, ensuring accessibility remains a key consideration in the decision-making process. By employing this hierarchical prioritization, our integrated model provides decision-makers with a comprehensive framework to make informed decisions aligned with organizational objectives and patient needs. Thus the priories of the models are as given below;

$$Z1 \gg Z3 \gg Z2$$

Where:

Z1: Maximum Weighted Traveled Distance

Z2 : Maximum Traveled Distance

Z3 : Total no show percentage

The following constraint was added to Z3 model to generate the required results

$$\sum_{i=1}^{|I|}\sum_{k=1}^{|K|} w_i d_{ik} X_{ik} \leq 1.15\ Z_{optimal} \qquad [9]$$

For Z2 model the following two constraints were added.

$$\sum_{i=1}^{|I|}\sum_{k=1}^{|K|} w_i d_{ik} X_{ik} \leq Z_{1\ optimal} \qquad [10]$$

$$\sum_{k=1}^{|K|} (5.513 U_k - 1.129 y_k) \leq Z_{13} \qquad [11]$$

4.5.1 Results and Discussion

The generated result from the above arrangement is as follows

Table 9. Integrated Model Results

Number of additional healthcare Centers	**Z1**	**Z3**	**Z2**	**Average Utilization %**
6	8,131,122.55	56.31%	8.00	88.82%
7	6,916,820.87	52.78%	7.80	82.45%
8	5,830,768.10	52.32%	7.80	77.37%
9	4,927,986.97	50.61%	7.80	73.07%

From the above results, we noticed that the optimal solution for Z1 and Z2 are inline with each other, and it does not violate any of the constrains. However, for Z3 a 15% allowable violation was allowed to get a solution to the model as the optimum value in model 1 (Z1) can’t be achieved by applying the no-show constraints of model 3 (Z3), by allowing this minor violation to the optimum value , the results reflects low no-show percentage which in the same range of the optimum values of model 3.

It is up to the decision maker to decide which objective function to prioritize and in both cases the average centers utilization will not be impacted.

CHAPTER 5: MULTI-PERIOD DYNAMIC CENTER LOCATION MODEL

To manage budget constraints and available resources effectively, a multi period phased model has been devised. This phased approach ensures a systematic allocation of resources over time, aligning with the project's financial limitations and resource availability. By breaking down the implementation process into manageable phases, the model allows for better control and optimization of expenditure while ensuring progress towards the overall project objectives. Each phase is carefully planned and executed, considering factors such as funding availability, resource capacity, and project priorities. This phased model enables decision-makers to allocate resources judiciously, mitigate financial risks, and optimize the utilization of available resources throughout the planning horizon.

The model has the following variables:

K: Set of candidates (or open) locations for the healthcare centers. (K = 1,2,3,..,87). first nine locations are currents open locations and the remaining locations are the center of zones as the candidate locations for new facilities)

T: set of time periods

I: Set of zones/ Sub-zones in Doha city. (I = 1,2,3,..,78)

To build the model, the following data was used:

w_{it} : Population per each zone i at year t.

C_{pk} : Health centers capacity for the health center at location k (open or to be opened)

d_{ik} : Distances from zone i to health center at location k.

u_{max} : Maximum utilization limit

u_{min} : Minimum utilization limit

α : number of centers allowed to be opened on a yearly bases.

5.1 Decision Variables

Decision variables of the model are;

$$Y_{kt} = \begin{cases} 1, \text{if helath center k is selected} \\ 0, otherwise \end{cases}$$

$$X_{ikt} = \begin{cases} 1, \text{if the demand point i is assigned to the Helath center k at time t} \\ 0, otherwise \end{cases}$$

5.2 Mathematical Model

Mathematical model of the problem based on p-median formulation is as follows;

$$Min\ Z = \sum_{i=1}^{|I|} \sum_{k=1}^{|K|} \sum_{t=1}^{|T|} w_{it} d_{ik} X_{ikt}$$

Subject to

$$\sum_{k=1}^{|K|} X_{ikt} = 1 \qquad \forall\ i \in I\ \&\ \forall \text{ t} \in \text{T} \qquad [1]$$

$$\sum_{i=1}^{|I|} X_{ikt} \leq y_{kt} \qquad \forall\ i \in \text{I} \quad \forall \text{ k} \in \text{K} \quad \forall \text{ t} \in \text{T} \qquad [2]$$

$$\sum_{\text{k}=1}^{|\text{K}|} Y_{kt} \leq P \qquad \forall \text{ t} \in \text{T} \qquad [3]$$

$$3.57\sum_{i=1}^{|I|} w_{it}X_{ikt} \leq cp_k y_{kt} \qquad \forall\ k \in K, \mathrm{t} \in \mathrm{T} \qquad [4]$$

$$3.57\sum_{i=1}^{|I|} w_{it}X_{ikt} \leq u\_\mathrm{max}\ cp_k Y_{kt} \qquad \forall\ k \in K, \mathrm{t} \in \mathrm{T} \qquad [5]$$

$$3.57\sum_{i=1}^{|I|} w_{it}X_{ikt} \geq u\_\mathrm{min}\ cp_k Y_{kt} \qquad for\ \forall\ k \in K \qquad [6]$$

$$\sum_{t=1}^{|T|} Y_{kt}\ = |T| \qquad \forall\ k \in \{1,2,..,9\} \qquad [7]$$

$$Y_{kt+1} \geq\ Y_{kt} \qquad \forall\ k \in K, \quad \forall\ \mathrm{t} \in [1-(\mathrm{T}-1)] \qquad [8]$$

$$\sum_{\mathrm{k}=1}^{|\mathrm{K}|} Y_{kt+1} - \sum_{\mathrm{k}=1}^{|\mathrm{K}|} Y_{kt} \leq \alpha \qquad \forall\ \mathrm{t} \in \mathrm{T} \qquad [9]$$

$$Y_{kt} \in \{0,1\}, X_{ikt} \in \{0,1\} \qquad \forall\ k \in K, i \in I \qquad [10]$$

The objective function is defined as the minimization of the total travelled distance by the population to reach the healthcare centers. Constrain set [1] assures that each zone is assigned to one health center at any point in times. Constraint set [2] restricts that the zone is assigned only to an open center at any point of time. Constraint set [3] restricts the number of centers to be open, [4] restricts the assignment of patients not to exceed annual capacity of open health centers. Constraints [5] and [6] restricts the upper and lower utilization limit. Constraint [7] makes sure that current healthcare centers are fixed as open, while constraint [8] restricts if a new center opens it remains open for the remaining duration. Constraint [9] allows alpha number of new centers to open in each period while constraint [7] is make the decision variables result binary

5.3 Results

An optimization software program, IBM ILOG CPLEX Optimization Studio 22.1.1, was used to develop, implement, and test the MILP models that were covered in this chapter and other earlier chapters. Results are presented on the effectiveness of MIP-based heuristics and optimality-based model solution.

The following assumptions were taken into consideration while building this model

1- Population yearly growth for the next 11 years were forecasted based on the census conducted by the authority in 2010 and 2015.

2- Considering 2024 as a starting point for the planning phase, Executing and opening a healthcare facility for the first year will be challenging requirement. Therefore, the model allows to open the first healthcare center starting from the 2026 onward.

3- The utilization limits for the existing and new centers shall remain within the limits demonstrated in the earlier chapters.

4- The model allows to re-allocate the patients on a yearly basis, considering the new centers open in the same year.

Based on the results from the previous sections, the model runs were arranged to prepare an eleven-years lookahead plan when to open the new healthcare centers considering 6,7,8 and 9 new centers to be added overall the full period. The results were generated based on two values for alpha (maximum allowed new healthcare centers to open from year to another) equal to two and three.

The graph below, reflects the result of the objective function (total weighted traveled distance) for opening six to nine new healthcare centers with a maximum allowed number of opening two to three centers.

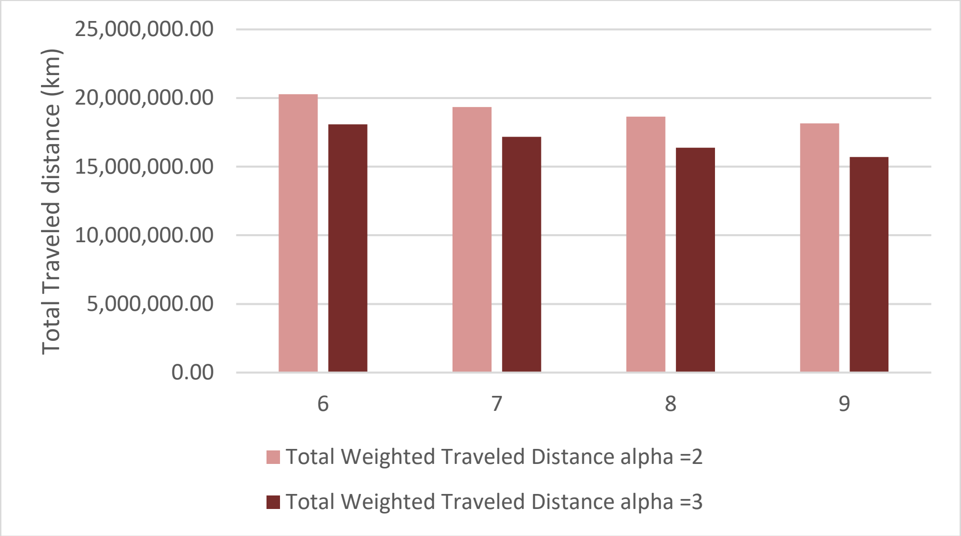

Figure 19. Total Weighted Traveled Distance Results (Z4)

The table below shows the phasewise opeing sequance based on the optimization model.

Table 10. Phasewise Healthcare Centers Opening

Number of additional healthcare Centers		2026	2027	2028	2029	2030
6	alpha =2	2	2	2	0	0
	alpha = 3	3	3	0	0	0
7	alpha =2	2	2	2	1	0
	alpha = 3	3	3	1	0	0
8	alpha =2	2	2	2	2	0
	alpha = 3	3	3	2	0	0
9	alpha =2	2	2	2	2	1
	alpha = 3	3	3	3	0	0

The above two results reflects clearly that opening healthcare centers at the earliest will reduce the travel distance and will satisfy the other sustainability factors and centers utilization limits. Table 10 and 11 reflects the location of the new centers which is planned to be opened throughout the period of 2026 until 2030. It can be observed that Zone 57m63,25 and 45 are common in all solutions and for all alpha values. It can be also noticed that the sequence of opening the new healthcare centers varies from solution to another which can be related to the expected population growth in specific zone in the year of opening to satisfy the demand with the same objective and constraints.

Table 11. Location of New Centers (1out Of 2)

Number of additional healthcare Centers	α		2026			2027	
6	alpha =2	Zone 57A	Zone 57 E		Zone 57H	Zone 63	
	alpha = 3	Zone 57B	Zone 57 I	Zone 63	Zone 57F	Zone 25 A	Zone 45 A
7	alpha =2	Zone 57A	Zone 57 E		Zone 57H	Zone 63	
	alpha = 3	Zone 57B	Zone 57 I	Zone 63	Zone 57F	Zone 25 A	Zone 45 A
8	alpha =2	Zone 57B	Zone 57 I		Zone 57D	Zone 63	
	alpha = 3	Zone 57B	Zone 57 E	Zone 63	Zone 57C	Zone 25 B	Zone 45 B
9	alpha =2	Zone 57A	Zone 57 E		Zone 57J	Zone 63	
	alpha = 3	Zone 57C	Zone 57 G	Zone 63	Zone 57J	Zone 25 B	Zone 45 A

Table 12. Location of New Centers (2 out of 2)

Number of additional healthcare Centers	α		2028			2029	2030
6	alpha =2	Zone 25C	Zone 45 C				
	alpha = 3	0					
7	alpha =2	Zone 25C	Zone 45 C		Zone 22		
	alpha = 3	Zone 22					
8	alpha =2	Zone 25 B	Zone 45 C		Zone 22	Zone 27B	
	alpha = 3	Zone 22	Zone 27B				
9	alpha =2	Zone 25 A	Zone 45 C		Zone 22	Zone 27B	Zone 34 A
	alpha = 3	Zone 22	Zone 34 A	Zone 27B			

CHAPTER 6: CONCLUSION AND FUTURE RESEARCH

In conclusion, this thesis has presented a comprehensive approach to optimizing the location of healthcare centers while incorporating environmental and social sustainability factors. Through the development of sophisticated optimization models, we have demonstrated the feasibility of enhancing healthcare access while minimizing environmental impact. The validation case study, focused on primary healthcare facilities in Qatar, underscored the effectiveness of our quantitative methods, resulting in the recommendation to open a minimum of six new healthcare centers and allocate patients accordingly.

Furthermore, the development of a phased plan model addresses the practical challenges of budget control and resource allocation, offering a structured approach to the implementation of healthcare center openings. By systematically phasing out the opening of new facilities, decision-makers can effectively manage financial constraints while ensuring progress towards improved healthcare accessibility.

Looking ahead, future research can expand upon this work by exploring additional factors that influence healthcare center location decisions, such as demographic trends, infrastructure development, and community preferences. Moreover, integrating advanced predictive analytics techniques could enhance the accuracy of population forecasting and optimize resource allocation strategies further. Additionally, considering the dynamic nature of healthcare systems, ongoing monitoring and evaluation mechanisms could be incorporated to assess the long-term effectiveness and sustainability of the proposed location optimization strategies. Overall, this research lays a solid foundation for future studies aimed at optimizing healthcare service delivery while promoting environmental and social sustainability.

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APPENDIX A : ZONE WISE POPULATION FORECAST FORM 2025 TO 2035

Zones	Forecasted Population for the Year of										
	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Zone 60	4391	4586	4781	4976	5172	5367	5605	5844	6083	6321	6560
Zone 61	9505	9927	10350	10773	11195	11618	12135	12651	13168	13684	14201
Zone 15	26914	28111	29308	30505	31701	32898	34361	35824	37287	38750	40212
Zone 57 A	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 57B	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 57C	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 57D	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 57E	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 57F	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 57G	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 57H	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 57I	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 57J	38351	40056	41762	43467	45172	46877	48962	51046	53131	55215	57300
Zone 2	10250	10706	11162	11618	12074	12529	13086	13644	14201	14758	15315
Zone 12	29	31	32	33	35	36	37	39	41	42	44
Zone 6	3856	4028	4199	4371	4542	4714	4923	5133	5343	5552	5762
Zone 16	23236	24270	25303	26336	27369	28403	29665	30928	32191	33454	34717
Zone 42	18898	19739	20579	21419	22260	23100	24127	25154	26181	27209	28236
Zone 1	161	169	176	183	190	197	206	215	224	232	241
Zone 28	2868	2995	3123	3250	3378	3505	3661	3817	3973	4129	4284
Zone 25A	26685	27871	29058	30244	31431	32617	34068	35518	36968	38419	39869
Zone 25 B	26685	27871	29058	30244	31431	32617	34068	35518	36968	38419	39869
Zone 25C	26685	27871	29058	30244	31431	32617	34068	35518	36968	38419	39869
Zone 33	13749	14360	14971	15583	16194	16805	17553	18300	19047	19794	20542
Zone 45 A	31281	32672	34063	35454	36845	38236	39936	41636	43336	45036	46736
Zone 45 B	31281	32672	34063	35454	36845	38236	39936	41636	43336	45036	46736
Zone 45 C	31281	32672	34063	35454	36845	38236	39936	41636	43336	45036	46736
Zone 36	11666	12185	12703	13222	13741	14260	14894	15528	16162	16796	17430

Zone 38	40505	42307	44108	45909	47710	49511	51712	53914	56115	58317	60518
Zone 39 A	22049	23029	24010	24990	25971	26951	28149	29348	30546	31745	32943
Zone 39 B	22049	23029	24010	24990	25971	26951	28149	29348	30546	31745	32943
Zone 40	28642	29915	31189	32462	33736	35009	36566	38123	39679	41236	42793
Zone 18	2652	2770	2888	3006	3124	3242	3386	3530	3675	3819	3963
Zone 7	64	66	69	72	75	78	81	85	88	92	95
Zone 46	27238	28449	29661	30872	32083	33294	34775	36255	37735	39216	40696
Zone 47	24668	25765	26861	27958	29055	30152	31493	32834	34174	35515	36856
Zone 30	9708	10139	10571	11003	11434	11866	12394	12921	13449	13977	14504
Zone 14	33632	35128	36623	38119	39614	41110	42938	44766	46594	48421	50249
Zone 22	23041	24065	25090	26114	27139	28163	29416	30668	31920	33173	34425
Zone 23	30623	31985	33346	34708	36070	37431	39096	40760	42424	44089	45753
Zone 37	40658	42466	44274	46082	47890	49698	51907	54117	56327	58537	60747
Zone 35	14416	15057	15698	16339	16980	17621	18405	19188	19972	20755	21539
Zone 3	203	212	221	230	239	248	259	270	281	292	303
Zone 67	13778	14391	15003	15616	16229	16841	17590	18339	19088	19837	20586
Zone 68	10857	11339	11822	12305	12788	13270	13861	14451	15041	15631	16221
Zone 64	5925	6188	6451	6715	6978	7242	7564	7886	8208	8530	8852
Zone 62	0	0	0	0	0	0	0	0	0	0	0
Zone 32	22789	23802	24816	25829	26842	27856	29094	30333	31572	32810	34049
Zone 34 A	18114	18920	19725	20531	21336	22142	23126	24111	25095	26080	27065
Zone 34 B	18114	18920	19725	20531	21336	22142	23126	24111	25095	26080	27065
Zone 34 C	18114	18920	19725	20531	21336	22142	23126	24111	25095	26080	27065
Zone 48	1136	1186	1237	1287	1338	1388	1450	1511	1573	1635	1697
Zone 49	2808	2933	3057	3182	3307	3432	3585	3737	3890	4042	4195
Zone 19	270	282	294	306	318	330	345	360	374	389	404
Zone 50	3698	3862	4026	4191	4355	4520	4721	4922	5122	5323	5524
Zone 4	4025	4204	4383	4562	4741	4920	5139	5358	5576	5795	6014
Zone 13	18565	19390	20216	21041	21867	22692	23701	24710	25719	26728	27737
Zone 26 A	26705	27892	29080	30267	31455	32642	34093	35545	36996	38448	39899
Zone 26 B	26705	27892	29080	30267	31455	32642	34093	35545	36996	38448	39899

Zone 41	9593	10019	10446	10872	11299	11726	12247	12768	13290	13811	14332
Zone 43	41444	43287	45130	46973	48816	50658	52911	55163	57416	59669	61921
Zone 44	24416	25502	26587	27673	28759	29844	31171	32498	33825	35152	36479
Zone 29	6008	6275	6542	6809	7076	7343	7670	7996	8323	8650	8976
Zone 24	33698	35197	36695	38194	39692	41190	43022	44853	46685	48517	50348
Zone 21	2421	2529	2637	2744	2852	2960	3091	3223	3355	3486	3618
Zone 27 A	24115	25187	26259	27331	28404	29476	30787	32097	33408	34719	36029
Zone 27 B	24115	25187	26259	27331	28404	29476	30787	32097	33408	34719	36029
Zone 31	20698	21618	22538	23459	24379	25299	26424	27549	28674	29799	30924
Zone 63	9180	9588	9996	10404	10812	11221	11719	12218	12717	13216	13715
Zone 65	9677	10107	10538	10968	11398	11829	12355	12881	13407	13933	14458
Zone 66 A	24300	25381	26462	27542	28623	29703	31024	32345	33665	34986	36307
Zone 66 B	24300	25381	26462	27542	28623	29703	31024	32345	33665	34986	36307
Zone 20	1034	1080	1126	1172	1218	1264	1320	1376	1433	1489	1545
Zone 69	10800	11281	11761	12241	12721	13202	13789	14376	14963	15550	16137
Zone 70 A	27883	29123	30363	31603	32843	34083	35598	37114	38629	40145	41660
Zone 70 B	27883	29123	30363	31603	32843	34083	35598	37114	38629	40145	41660
Zone 70 C	27883	29123	30363	31603	32843	34083	35598	37114	38629	40145	41660
Zone 70 D	27883	29123	30363	31603	32843	34083	35598	37114	38629	40145	41660

APPENDIX B : DISTANCES FROM EACH DEMAND POINT TO POTENTIAL POINTS TO LOCATE HEALTHCARE CENTERS

Zone	Centers Capacity	Zone 60	Zone 61	Zone 15	Zone 57 A	Zone 57 B	Zone 57 C	Zone 57 D
Qatar University Health Center	500	14.9	14.8	22.8	31.6	31.6	31.6	31.6
Al WAAB HC	500	12.1	14.8	10.4	11.2	11.2	11.2	11.2
Airport HC	750	9.6	14.3	4.3	19.6	19.6	19.6	19.6
Rawdat Alkahil HC	1000	9.5	12.6	5.8	27.7	27.7	27.7	27.7
madinat Khalifa HC	750	5.1	9.6	14.7	23.1	23.1	23.1	23.1
AlThumama HC	750	17.1	19.7	14.1	17.5	17.5	17.5	17.5
Omar Bin Alkhattab HC	500	10	10.1	5.1	16.3	16.3	16.3	16.3
Umm Ghuwailina HC	750	2.8	4.7	5	21.8	21.8	21.8	21.8
WastBay HC	1000	6.1	6.7	10.8	30.9	30.9	30.9	30.9
Zone 60	750	0.00	0.94	2.00	8.57	8.57	8.57	8.57
Zone 61	750	0.94	0.00	2.90	9.13	9.13	9.13	9.13
Zone 15	750	2.00	2.90	0.00	7.01	7.01	7.01	7.01
Zone 57A	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 57B	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 57C	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 57D	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 57E	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 57F	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 57G	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 57H	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 57I	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 57J	750	8.57	9.13	7.01	0.00	0.00	0.00	0.00
Zone 2	750	1.20	2.02	0.92	7.44	7.44	7.44	7.44
Zone 12	750	1.53	2.00	1.61	7.13	7.13	7.13	7.13
Zone 6	750	1.26	2.20	0.99	7.97	7.97	7.97	7.97
Zone 16	750	1.96	2.89	0.68	7.59	7.59	7.59	7.59
Zone 42	750	2.83	3.77	1.11	7.20	7.20	7.20	7.20
Zone 1	750	1.31	2.23	1.16	8.16	8.16	8.16	8.16
Zone 28	750	1.70	2.37	2.28	9.28	9.28	9.28	9.28
Zone 25 A	750	2.20	3.09	0.20	6.89	6.89	6.89	6.89
Zone 25 B	750	2.20	3.09	0.20	6.89	6.89	6.89	6.89
Zone 25C	750	2.20	3.09	0.20	6.89	6.89	6.89	6.89
Zone 33	750	2.63	2.20	3.72	8.13	8.13	8.13	8.13
Zone 45 A	750	3.10	4.04	1.37	7.17	7.17	7.17	7.17

Zone 45 B	750	3.10	4.04	1.37	7.17	7.17	7.17	7.17
Zone 45 C	750	3.10	4.04	1.37	7.17	7.17	7.17	7.17
Zone 36	750	3.30	3.41	3.23	6.19	6.19	6.19	6.19
Zone 38	750	2.53	2.78	2.43	6.47	6.47	6.47	6.47
Zone 39 A	750	2.59	3.29	1.19	6.02	6.02	6.02	6.02
Zone 39 B	750	2.59	3.29	1.19	6.02	6.02	6.02	6.02
Zone 40	750	3.15	3.92	1.38	5.63	5.63	5.63	5.63
Zone 18	750	1.08	1.94	1.60	8.58	8.58	8.58	8.58
Zone 7	750	1.24	2.17	1.12	8.11	8.11	8.11	8.11
Zone 46	750	3.99	4.91	2.04	6.35	6.35	6.35	6.35
Zone 47	750	4.03	4.96	2.38	7.44	7.44	7.44	7.44
Zone 30	750	5.41	4.73	6.60	9.65	9.65	9.65	9.65
Zone 14	750	2.03	2.89	0.28	6.81	6.81	6.81	6.81
Zone 22	750	1.89	2.45	1.42	6.70	6.70	6.70	6.70
Zone 23	750	2.30	2.99	1.12	6.28	6.28	6.28	6.28
Zone 37	750	2.49	2.20	3.39	7.76	7.76	7.76	7.76
Zone 35	750	2.49	2.38	3.09	7.29	7.29	7.29	7.29
Zone 3	750	0.79	1.58	1.34	7.79	7.79	7.79	7.79
Zone 67	750	3.15	2.47	4.53	8.97	8.97	8.97	8.97
Zone 68	750	3.76	2.91	5.40	10.08	10.08	10.08	10.08
Zone 64	750	1.76	1.37	3.06	8.26	8.26	8.26	8.26
Zone 62	750	3.64	3.26	4.42	7.75	7.75	7.75	7.75
Zone 32	750	3.37	3.21	3.82	7.02	7.02	7.02	7.02
Zone 34 A	750	3.81	4.68	2.85	8.84	8.84	8.84	8.84
Zone 34 B	750	3.81	4.68	2.85	8.84	8.84	8.84	8.84
Zone 34 C	750	3.81	4.68	2.85	8.84	8.84	8.84	8.84
Zone 48	750	4.86	5.52	4.57	10.84	10.84	10.84	10.84
Zone 49	750	1.53	2.31	1.91	8.92	8.92	8.92	8.92
Zone 19	750	5.24	6.17	3.66	7.92	7.92	7.92	7.92
Zone 50	750	1.85	2.73	0.17	7.09	7.09	7.09	7.09
Zone 4	750	1.20	1.94	1.11	7.38	7.38	7.38	7.38
Zone 13	750	2.23	3.16	0.70	7.43	7.43	7.43	7.43
Zone 26 A	750	2.84	3.73	0.84	6.49	6.49	6.49	6.49
Zone 26 B	750	2.84	3.73	0.84	6.49	6.49	6.49	6.49
Zone 41	750	3.43	4.21	1.61	5.41	5.41	5.41	5.41
Zone 43	750	3.12	4.01	1.12	6.29	6.29	6.29	6.29
Zone 44	750	2.52	3.08	3.02	9.99	9.99	9.99	9.99
Zone 29	750	2.17	3.03	0.29	6.73	6.73	6.73	6.73
Zone 24	750	1.81	2.33	1.52	6.81	6.81	6.81	6.81
Zone 21	750	2.16	3.10	0.90	7.68	7.68	7.68	7.68
Zone 27	750	4.15	3.58	5.22	8.63	8.63	8.63	8.63
Zone 31	750	1.11	0.39	2.94	8.91	8.91	8.91	8.91
Zone 63	750	1.83	1.18	3.38	8.75	8.75	8.75	8.75
Zone 65	750	4.66	3.91	6.63	13.00	13.00	13.00	13.00

Zone 66 A	750	1.00	1.20	2.11	7.92	7.92	7.92	7.92
Zone 66 B	750	1.00	1.20	2.11	7.92	7.92	7.92	7.92
Zone 20	750	2.52	3.08	3.02	9.99	9.99	9.99	9.99
Zone 69	750	2.17	3.03	0.29	6.73	6.73	6.73	6.73
Zone 70 A	750	1.81	2.33	1.52	6.81	6.81	6.81	6.81
Zone 70 B	750	1.81	2.33	1.52	6.81	6.81	6.81	6.81
Zone 70 C	750	1.81	2.33	1.52	6.81	6.81	6.81	6.81
Zone 70 D	750	1.81	2.33	1.52	6.81	6.81	6.81	6.81

Zone 57 E	Zone 57 F	Zone 57 G	Zone 57 H	Zone 57 I	Zone 57 J	Zone 2	Zone 12	Zone 6
31.6	31.6	31.6	31.6	31.6	31.6	18	16.7	14.4
11.2	11.2	11.2	11.2	11.2	11.2	11	10.9	12.9
19.6	19.6	19.6	19.6	19.6	19.6	8	10.7	8
27.7	27.7	27.7	27.7	27.7	27.7	6.7	9.2	5.1
23.1	23.1	23.1	23.1	23.1	23.1	9.8	7.4	11.7
17.5	17.5	17.5	17.5	17.5	17.5	15.9	18.6	13.3
16.3	16.3	16.3	16.3	16.3	16.3	6.1	6.4	6.5
21.8	21.8	21.8	21.8	21.8	21.8	2.9	1	4.4
30.9	30.9	30.9	30.9	30.9	30.9	8.5	7.9	10.8
8.57	8.57	8.57	8.57	8.57	8.57	1.20	1.53	1.26
9.13	9.13	9.13	9.13	9.13	9.13	2.02	2.00	2.20
7.01	7.01	7.01	7.01	7.01	7.01	0.92	1.61	0.99
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
0.00	0.00	0.00	0.00	0.00	0.00	7.44	7.13	7.97
7.44	7.44	7.44	7.44	7.44	7.44	0.00	0.90	0.84
7.13	7.13	7.13	7.13	7.13	7.13	0.90	0.00	1.72
7.97	7.97	7.97	7.97	7.97	7.97	0.84	1.72	0.00
7.59	7.59	7.59	7.59	7.59	7.59	1.21	2.07	0.70
7.20	7.20	7.20	7.20	7.20	7.20	1.96	2.72	1.58
8.16	8.16	8.16	8.16	8.16	8.16	1.05	1.93	0.22
9.28	9.28	9.28	9.28	9.28	9.28	2.10	2.89	1.35
6.89	6.89	6.89	6.89	6.89	6.89	1.11	1.76	1.15
6.89	6.89	6.89	6.89	6.89	6.89	1.11	1.76	1.15
6.89	6.89	6.89	6.89	6.89	6.89	1.11	1.76	1.15
8.13	8.13	8.13	8.13	8.13	8.13	2.89	2.13	3.57

7.17	7.17	7.17	7.17	7.17	7.17	2.23	2.98	1.85
7.17	7.17	7.17	7.17	7.17	7.17	2.23	2.98	1.85
7.17	7.17	7.17	7.17	7.17	7.17	2.23	2.98	1.85
6.19	6.19	6.19	6.19	6.19	6.19	2.77	1.91	3.61
6.47	6.47	6.47	6.47	6.47	6.47	1.94	1.08	2.77
6.02	6.02	6.02	6.02	6.02	6.02	1.43	1.38	2.02
6.02	6.02	6.02	6.02	6.02	6.02	1.43	1.38	2.02
5.63	5.63	5.63	5.63	5.63	5.63	1.95	2.07	2.35
8.58	8.58	8.58	8.58	8.58	8.58	1.29	2.08	0.61
8.11	8.11	8.11	8.11	8.11	8.11	0.96	1.83	0.15
6.35	6.35	6.35	6.35	6.35	6.35	2.96	3.54	2.78
7.44	7.44	7.44	7.44	7.44	7.44	3.23	3.99	2.77
9.65	9.65	9.65	9.65	9.65	9.65	5.78	5.00	6.45
6.81	6.81	6.81	6.81	6.81	6.81	0.87	1.42	1.16
6.70	6.70	6.70	6.70	6.70	6.70	0.97	0.46	1.80
6.28	6.28	6.28	6.28	6.28	6.28	1.17	1.08	1.83
7.76	7.76	7.76	7.76	7.76	7.76	2.59	1.78	3.32
7.29	7.29	7.29	7.29	7.29	7.29	2.36	1.49	3.15
7.79	7.79	7.79	7.79	7.79	7.79	0.44	0.89	0.96
8.97	8.97	8.97	8.97	8.97	8.97	3.65	2.98	4.25
10.08	10.08	10.08	10.08	10.08	10.08	4.49	3.93	4.97
8.26	8.26	8.26	8.26	8.26	8.26	2.17	1.57	2.77
7.75	7.75	7.75	7.75	7.75	7.75	3.69	2.83	4.45
7.02	7.02	7.02	7.02	7.02	7.02	3.18	2.28	3.99
8.84	8.84	8.84	8.84	8.84	8.84	3.44	4.32	2.70
8.84	8.84	8.84	8.84	8.84	8.84	3.44	4.32	2.70
8.84	8.84	8.84	8.84	8.84	8.84	3.44	4.32	2.70
10.84	10.84	10.84	10.84	10.84	10.84	4.92	5.81	4.09
8.92	8.92	8.92	8.92	8.92	8.92	1.77	2.59	0.99
7.92	7.92	7.92	7.92	7.92	7.92	4.50	5.26	3.99
7.09	7.09	7.09	7.09	7.09	7.09	0.75	1.47	0.89
7.38	7.38	7.38	7.38	7.38	7.38	0.26	0.65	1.08
7.43	7.43	7.43	7.43	7.43	7.43	1.41	2.24	0.98
6.49	6.49	6.49	6.49	6.49	6.49	1.74	2.29	1.74
6.49	6.49	6.49	6.49	6.49	6.49	1.74	2.29	1.74
5.41	5.41	5.41	5.41	5.41	5.41	2.23	2.36	2.60
6.29	6.29	6.29	6.29	6.29	6.29	2.01	2.52	2.02
9.99	9.99	9.99	9.99	9.99	9.99	2.96	3.76	2.17
6.73	6.73	6.73	6.73	6.73	6.73	1.01	1.55	1.25
6.81	6.81	6.81	6.81	6.81	6.81	0.99	0.33	1.83
7.68	7.68	7.68	7.68	7.68	7.68	1.48	2.34	0.90
8.63	8.63	8.63	8.63	8.63	8.63	4.42	3.61	5.12
8.91	8.91	8.91	8.91	8.91	8.91	2.03	1.84	2.35
8.75	8.75	8.75	8.75	8.75	8.75	2.47	1.98	2.97

13.00	13.00	13.00	13.00	13.00	13.00	5.86	5.91	5.73
7.92	7.92	7.92	7.92	7.92	7.92	1.20	0.82	1.80
7.92	7.92	7.92	7.92	7.92	7.92	1.20	0.82	1.80
9.99	9.99	9.99	9.99	9.99	9.99	2.96	3.76	2.17
6.73	6.73	6.73	6.73	6.73	6.73	1.01	1.55	1.25
6.81	6.81	6.81	6.81	6.81	6.81	0.99	0.33	1.83
6.81	6.81	6.81	6.81	6.81	6.81	0.99	0.33	1.83
6.81	6.81	6.81	6.81	6.81	6.81	0.99	0.33	1.83
6.81	6.81	6.81	6.81	6.81	6.81	0.99	0.33	1.83

Zone 16	Zone 42	Zone 1	Zone 28	Zone 25 A	Zone 25 B	Zone 25 C	Zone 33	Zone 45 A
19.4	22.9	19.2	23	22.6	22.6	22.6	7.1	22.6
11.2	13.3	12.2	14	13	13	13	15.5	13
4	4.4	6.7	5.2	6.8	6.8	6.8	18.7	4.1
3.9	5.7	5.5	2.8	6.1	6.1	6.1	14.1	6.9
10.9	14.8	11.1	19	14.4	14.4	14.4	4.7	17.6
13.3	7.1	14.6	12.9	8.3	8.3	8.3	23.1	7.9
7	5	6.4	10.6	6	6	6	12.2	6.1
4.8	6.7	3.3	6.1	4.5	4.5	4.5	6.9	7.6
10.7	16.8	9.7	12.6	10.8	10.8	10.8	5	22
1.96	2.83	1.31	1.70	2.20	2.20	2.20	2.63	3.10
2.89	3.77	2.23	2.37	3.09	3.09	3.09	2.20	4.04
0.68	1.11	1.16	2.28	0.20	0.20	0.20	3.72	1.37
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
7.59	7.20	8.16	9.28	6.89	6.89	6.89	8.13	7.17
1.21	1.96	1.05	2.10	1.11	1.11	1.11	2.89	2.23
2.07	2.72	1.93	2.89	1.76	1.76	1.76	2.13	2.98
0.70	1.58	0.22	1.35	1.15	1.15	1.15	3.57	1.85
0.00	0.88	0.75	1.72	0.73	0.73	0.73	4.10	1.15
0.88	0.00	1.61	2.39	0.98	0.98	0.98	4.83	0.28
0.75	1.61	0.00	1.14	1.30	1.30	1.30	3.73	1.86
1.72	2.39	1.14	0.00	2.40	2.40	2.40	4.33	2.59
0.73	0.98	1.30	2.40	0.00	0.00	0.00	3.89	1.23
0.73	0.98	1.30	2.40	0.00	0.00	0.00	3.89	1.23
0.73	0.98	1.30	2.40	0.00	0.00	0.00	3.89	1.23

4.10	4.83	3.73	4.33	3.89	3.89	3.89	0.00	5.09
1.15	0.28	1.86	2.59	1.23	1.23	1.23	5.09	0.00
1.15	0.28	1.86	2.59	1.23	1.23	1.23	5.09	0.00
1.15	0.28	1.86	2.59	1.23	1.23	1.23	5.09	0.00
3.83	4.28	3.83	4.80	3.31	3.31	3.31	1.94	4.50
3.01	3.51	2.99	3.97	2.53	2.53	2.53	1.88	3.74
1.87	2.05	2.23	3.37	1.18	1.18	1.18	3.34	2.24
1.87	2.05	2.23	3.37	1.18	1.18	1.18	3.34	2.24
1.99	1.86	2.54	3.66	1.27	1.27	1.27	4.04	1.97
1.20	2.04	0.46	0.82	1.75	1.75	1.75	3.66	2.28
0.77	1.64	0.10	1.21	1.27	1.27	1.27	3.63	1.90
2.09	1.25	2.84	3.63	1.85	1.85	1.85	5.66	1.05
2.09	1.28	2.73	3.20	2.24	2.24	2.24	6.10	1.01
6.99	7.71	6.59	7.06	6.76	6.76	6.76	2.89	7.97
0.95	1.34	1.36	2.49	0.36	0.36	0.36	3.55	1.58
1.99	2.51	2.02	3.07	1.53	1.53	1.53	2.46	2.76
1.78	2.10	2.05	3.18	1.16	1.16	1.16	3.09	2.32
3.80	4.50	3.49	4.18	3.55	3.55	3.55	0.41	4.76
3.56	4.20	3.33	4.13	3.23	3.23	3.23	0.89	4.46
1.52	2.33	1.14	2.01	1.54	1.54	1.54	2.61	2.61
4.83	5.61	4.37	4.80	4.70	4.70	4.70	0.93	5.88
5.61	6.44	5.06	5.27	5.59	5.59	5.59	2.02	6.71
3.35	4.13	2.91	3.46	3.24	3.24	3.24	0.88	4.41
4.89	5.53	4.62	5.33	4.56	4.56	4.56	1.07	5.79
4.35	4.92	4.18	5.01	3.94	3.94	3.94	1.25	5.16
2.26	1.91	2.56	2.46	2.78	2.78	2.78	6.27	1.80
2.26	1.91	2.56	2.46	2.78	2.78	2.78	6.27	1.80
2.26	1.91	2.56	2.46	2.78	2.78	2.78	6.27	1.80
3.90	3.82	3.88	3.18	4.56	4.56	4.56	7.49	3.76
1.37	2.08	0.78	0.36	2.03	2.03	2.03	4.15	2.29
3.34	2.55	3.93	4.21	3.50	3.50	3.50	7.38	2.28
0.71	1.26	1.08	2.21	0.36	0.36	0.36	3.57	1.52
1.46	2.18	1.29	2.30	1.29	1.29	1.29	2.65	2.46
0.28	0.61	1.02	1.94	0.67	0.67	0.67	4.30	0.88
1.16	0.81	1.86	2.88	0.64	0.64	0.64	4.41	0.94
1.16	0.81	1.86	2.88	0.64	0.64	0.64	4.41	0.94
2.18	1.94	2.77	3.88	1.48	1.48	1.48	4.30	2.02
1.41	0.92	2.13	3.13	0.92	0.92	0.92	4.64	0.97
2.40	2.89	1.95	0.87	3.12	3.12	3.12	5.14	3.02
0.96	1.24	1.43	2.56	0.27	0.27	0.27	3.68	1.48
2.07	2.63	2.05	3.07	1.65	1.65	1.65	2.31	2.88
0.27	0.72	0.89	1.71	0.90	0.90	0.90	4.36	0.97
5.63	6.33	5.27	5.83	5.37	5.37	5.37	1.54	6.59
3.02	3.88	2.42	2.69	3.13	3.13	3.13	1.81	4.16

3.60	4.42	3.08	3.47	3.57	3.57	3.57	1.06	4.69
6.41	7.25	5.66	5.03	6.82	6.82	6.82	5.19	7.49
2.37	3.16	1.95	2.64	2.29	2.29	2.29	1.77	3.43
2.37	3.16	1.95	2.64	2.29	2.29	2.29	1.77	3.43
2.40	2.89	1.95	0.87	3.12	3.12	3.12	5.14	3.02
0.96	1.24	1.43	2.56	0.27	0.27	0.27	3.68	1.48
2.07	2.63	2.05	3.07	1.65	1.65	1.65	2.31	2.88
2.07	2.63	2.05	3.07	1.65	1.65	1.65	2.31	2.88
2.07	2.63	2.05	3.07	1.65	1.65	1.65	2.31	2.88
2.07	2.63	2.05	3.07	1.65	1.65	1.65	2.31	2.88

Zone 45 B	Zone 45 C	Zone 36	Zone 38	Zone 39 A	Zone 39 B	Zone 40	Zone 18	Zone 7
22.6	22.6	12.9	15.8	17.9	17.9	19.8	16.4	22.8
13	13	11.6	7.8	8.7	8.7	8	14.3	12.7
4.1	4.1	14.8	11.6	11.8	11.8	7.1	7.8	7.2
6.9	6.9	12.2	10.5	10.1	10.1	8.5	3.8	4
17.6	17.6	5.8	9.9	12.3	12.3	11.2	11.9	11.6
7.9	7.9	15.9	12.9	12	12	10.4	13.2	13.5
6.1	6.1	8.3	9.8	4.2	4.2	2.1	7	6.4
7.6	7.6	6.7	5.1	6.2	6.2	5.8	4.1	3.9
22	22	8.8	15.1	16.9	16.9	18.5	11.2	10.2
3.10	3.10	3.30	2.53	2.59	2.59	3.15	1.08	1.24
4.04	4.04	3.41	2.78	3.29	3.29	3.92	1.94	2.17
1.37	1.37	3.23	2.43	1.19	1.19	1.38	1.60	1.12
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
7.17	7.17	6.19	6.47	6.02	6.02	5.63	8.58	8.11
2.23	2.23	2.77	1.94	1.43	1.43	1.95	1.29	0.96
2.98	2.98	1.91	1.08	1.38	1.38	2.07	2.08	1.83
1.85	1.85	3.61	2.77	2.02	2.02	2.35	0.61	0.15
1.15	1.15	3.83	3.01	1.87	1.87	1.99	1.20	0.77
0.28	0.28	4.28	3.51	2.05	2.05	1.86	2.04	1.64
1.86	1.86	3.83	2.99	2.23	2.23	2.54	0.46	0.10
2.59	2.59	4.80	3.97	3.37	3.37	3.66	0.82	1.21
1.23	1.23	3.31	2.53	1.18	1.18	1.27	1.75	1.27
1.23	1.23	3.31	2.53	1.18	1.18	1.27	1.75	1.27

1.23	1.23	3.31	2.53	1.18	1.18	1.27	1.75	1.27
5.09	5.09	1.94	1.88	3.34	3.34	4.04	3.66	3.63
0.00	0.00	4.50	3.74	2.24	2.24	1.97	2.28	1.90
0.00	0.00	4.50	3.74	2.24	2.24	1.97	2.28	1.90
0.00	0.00	4.50	3.74	2.24	2.24	1.97	2.28	1.90
4.50	4.50	0.00	0.84	2.29	2.29	2.85	3.99	3.73
3.74	3.74	0.84	0.00	1.63	1.63	2.28	3.16	2.89
2.24	2.24	2.29	1.63	0.00	0.00	0.70	2.60	2.16
2.24	2.24	2.29	1.63	0.00	0.00	0.70	2.60	2.16
1.97	1.97	2.85	2.28	0.70	0.70	0.00	2.96	2.49
2.28	2.28	3.99	3.16	2.60	2.60	2.96	0.00	0.48
1.90	1.90	3.73	2.89	2.16	2.16	2.49	0.48	0.00
1.05	1.05	4.71	4.06	2.44	2.44	1.89	3.28	2.86
1.01	1.01	5.46	4.73	3.18	3.18	2.78	3.10	2.79
7.97	7.97	4.06	4.47	6.08	6.08	6.74	6.47	6.50
1.58	1.58	2.96	2.18	0.92	0.92	1.20	1.77	1.30
2.76	2.76	1.85	1.03	0.94	0.94	1.64	2.25	1.93
2.32	2.32	2.18	1.45	0.30	0.30	0.99	2.40	1.98
4.76	4.76	1.58	1.47	2.95	2.95	3.65	3.46	3.39
4.46	4.46	1.15	0.99	2.53	2.53	3.21	3.37	3.24
2.61	2.61	2.79	1.96	1.80	1.80	2.37	1.21	1.04
5.88	5.88	2.80	2.80	4.25	4.25	4.95	4.22	4.28
6.71	6.71	3.91	3.89	5.26	5.26	5.97	4.83	4.98
4.41	4.41	2.22	1.80	2.93	2.93	3.63	2.81	2.82
5.79	5.79	1.77	2.16	3.79	3.79	4.44	4.61	4.53
5.16	5.16	0.96	1.44	3.06	3.06	3.68	4.25	4.08
1.80	1.80	6.07	5.26	3.94	3.94	3.76	2.74	2.65
1.80	1.80	6.07	5.26	3.94	3.94	3.76	2.74	2.65
1.80	1.80	6.07	5.26	3.94	3.94	3.76	2.74	2.65
3.76	3.76	7.69	6.85	5.74	5.74	5.67	3.84	3.98
2.29	2.29	4.50	3.67	3.01	3.01	3.29	0.52	0.85
2.28	2.28	6.69	5.98	4.39	4.39	3.92	4.26	4.00
1.52	1.52	3.14	2.33	1.19	1.19	1.46	1.50	1.03
2.46	2.46	2.54	1.70	1.39	1.39	1.98	1.48	1.19
0.88	0.88	3.93	3.12	1.85	1.85	1.87	1.47	1.04
0.94	0.94	3.61	2.90	1.33	1.33	1.04	2.32	1.85
0.94	0.94	3.61	2.90	1.33	1.33	1.04	2.32	1.85
2.02	2.02	3.03	2.51	0.98	0.98	0.29	3.21	2.73
0.97	0.97	3.74	3.06	1.45	1.45	1.02	2.59	2.12
3.02	3.02	5.67	4.84	4.17	4.17	4.39	1.68	2.03
1.48	1.48	3.04	2.27	0.92	0.92	1.11	1.86	1.39
2.88	2.88	1.79	0.95	1.09	1.09	1.79	2.25	1.95
0.97	0.97	4.09	3.27	2.07	2.07	2.12	1.32	0.94
6.59	6.59	2.74	3.08	4.69	4.69	5.36	5.19	5.18

4.16	4.16	3.09	2.50	3.19	3.19	3.84	2.18	2.35
4.69	4.69	2.68	2.28	3.36	3.36	4.06	2.90	2.99
7.49	7.49	7.00	6.55	7.20	7.20	7.80	5.22	5.64
3.43	3.43	2.34	1.62	2.18	2.18	2.85	1.91	1.86
3.43	3.43	2.34	1.62	2.18	2.18	2.85	1.91	1.86
3.02	3.02	5.67	4.84	4.17	4.17	4.39	1.68	2.03
1.48	1.48	3.04	2.27	0.92	0.92	1.11	1.86	1.39
2.88	2.88	1.79	0.95	1.09	1.09	1.79	2.25	1.95
2.88	2.88	1.79	0.95	1.09	1.09	1.79	2.25	1.95
2.88	2.88	1.79	0.95	1.09	1.09	1.79	2.25	1.95
2.88	2.88	1.79	0.95	1.09	1.09	1.79	2.25	1.95

Zone 46	Zone 47	Zone 30	Zone 14	Zone 22	Zone 23	Zone 37	Zone 35	Zone 3
23.7	22.9	6.5	17.8	18.8	17.6	13.9	12.9	13.8
13	13.4	19.5	10.7	9.8	9.2	11.8	13.3	11.7
7	1.7	26.3	8.7	9.4	7.7	13.1	16.4	5.8
8.7	8.3	25	6.7	9.1	7.3	11.2	11.8	6.4
17.3	17	11.8	10.6	8.7	9.4	5.5	4.3	9.3
7.4	4.6	26.1	14.8	13.6	12	15.3	20.6	15.3
6	7.1	17.6	4.3	5	3.2	7	9.8	5.3
12.7	9.4	16	4.6	3.2	4	5.7	4.6	3.2
21.9	23	9.5	10.5	9.6	9.2	7.4	7.4	9.4
3.99	4.03	5.41	2.03	1.89	2.30	2.49	2.49	0.79
4.91	4.96	4.73	2.89	2.45	2.99	2.20	2.38	1.58
2.04	2.38	6.60	0.28	1.42	1.12	3.39	3.09	1.34
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
6.35	7.44	9.65	6.81	6.70	6.28	7.76	7.29	7.79
2.96	3.23	5.78	0.87	0.97	1.17	2.59	2.36	0.44
3.54	3.99	5.00	1.42	0.46	1.08	1.78	1.49	0.89
2.78	2.77	6.45	1.16	1.80	1.83	3.32	3.15	0.96
2.09	2.09	6.99	0.95	1.99	1.78	3.80	3.56	1.52
1.25	1.28	7.71	1.34	2.51	2.10	4.50	4.20	2.33
2.84	2.73	6.59	1.36	2.02	2.05	3.49	3.33	1.14
3.63	3.20	7.06	2.49	3.07	3.18	4.18	4.13	2.01
1.85	2.24	6.76	0.36	1.53	1.16	3.55	3.23	1.54

1.85	2.24	6.76	0.36	1.53	1.16	3.55	3.23	1.54
1.85	2.24	6.76	0.36	1.53	1.16	3.55	3.23	1.54
5.66	6.10	2.89	3.55	2.46	3.09	0.41	0.89	2.61
1.05	1.01	7.97	1.58	2.76	2.32	4.76	4.46	2.61
1.05	1.01	7.97	1.58	2.76	2.32	4.76	4.46	2.61
1.05	1.01	7.97	1.58	2.76	2.32	4.76	4.46	2.61
4.71	5.46	4.06	2.96	1.85	2.18	1.58	1.15	2.79
4.06	4.73	4.47	2.18	1.03	1.45	1.47	0.99	1.96
2.44	3.18	6.08	0.92	0.94	0.30	2.95	2.53	1.80
2.44	3.18	6.08	0.92	0.94	0.30	2.95	2.53	1.80
1.89	2.78	6.74	1.20	1.64	0.99	3.65	3.21	2.37
3.28	3.10	6.47	1.77	2.25	2.40	3.46	3.37	1.21
2.86	2.79	6.50	1.30	1.93	1.98	3.39	3.24	1.04
0.00	1.11	8.48	2.14	3.20	2.62	5.29	4.92	3.38
1.11	0.00	8.99	2.59	3.76	3.29	5.78	5.46	3.59
8.48	8.99	0.00	6.41	5.28	5.86	3.21	3.56	5.49
2.14	2.59	6.41	0.00	1.18	0.84	3.20	2.88	1.31
3.20	3.76	5.28	1.18	0.00	0.64	2.09	1.72	1.15
2.62	3.29	5.86	0.84	0.64	0.00	2.70	2.30	1.52
5.29	5.78	3.21	3.20	2.09	2.70	0.00	0.49	2.36
4.92	5.46	3.56	2.88	1.72	2.30	0.49	0.00	2.20
3.38	3.59	5.49	1.31	1.15	1.52	2.36	2.20	0.00
6.51	6.89	2.27	4.38	3.35	3.98	1.34	1.82	3.31
7.43	7.70	2.19	5.28	4.34	4.98	2.43	2.92	4.10
5.07	5.41	3.68	2.93	2.00	2.64	0.83	1.09	1.83
6.21	6.80	2.31	4.21	3.04	3.58	1.15	1.33	3.49
5.50	6.15	3.11	3.58	2.40	2.89	1.04	0.89	3.06
2.48	1.45	9.15	3.12	4.24	3.94	6.01	5.80	3.66
2.48	1.45	9.15	3.12	4.24	3.94	6.01	5.80	3.66
2.48	1.45	9.15	3.12	4.24	3.94	6.01	5.80	3.66
4.49	3.42	10.24	4.85	5.84	5.68	7.31	7.20	5.00
3.33	2.97	6.94	2.13	2.75	2.83	3.97	3.89	1.72
2.06	1.27	10.26	3.86	5.02	4.53	7.05	6.73	4.85
2.21	2.53	6.45	0.28	1.30	1.07	3.25	2.95	1.18
3.14	3.46	5.54	1.00	0.78	1.11	2.35	2.11	0.41
1.81	1.84	7.19	0.98	2.10	1.81	3.99	3.73	1.75
1.25	1.85	7.25	0.90	1.98	1.45	4.06	3.70	2.17
1.25	1.85	7.25	0.90	1.98	1.45	4.06	3.70	2.17
1.78	2.75	6.98	1.45	1.92	1.28	3.91	3.47	2.66
1.02	1.77	7.46	1.16	2.18	1.61	4.27	3.90	2.45
4.06	3.40	7.81	3.26	3.93	4.00	5.01	4.99	2.88
2.00	2.48	6.54	0.15	1.28	0.88	3.33	2.99	1.45
3.35	3.89	5.14	1.30	0.16	0.80	1.94	1.58	1.11
1.97	1.86	7.25	1.17	2.25	2.01	4.07	3.83	1.77

7.09	7.61	1.39	5.03	3.89	4.47	1.83	2.17	4.15
4.98	5.11	4.38	2.89	2.30	2.88	1.81	2.02	1.59
5.42	5.68	3.59	3.28	2.42	3.06	1.18	1.53	2.08
8.50	8.22	6.05	6.69	6.36	6.90	5.46	5.85	5.43
4.14	4.43	4.65	2.00	1.28	1.87	1.55	1.49	0.85
4.14	4.43	4.65	2.00	1.28	1.87	1.55	1.49	0.85
4.06	3.40	7.81	3.26	3.93	4.00	5.01	4.99	2.88
2.00	2.48	6.54	0.15	1.28	0.88	3.33	2.99	1.45
3.35	3.89	5.14	1.30	0.16	0.80	1.94	1.58	1.11
3.35	3.89	5.14	1.30	0.16	0.80	1.94	1.58	1.11
3.35	3.89	5.14	1.30	0.16	0.80	1.94	1.58	1.11
3.35	3.89	5.14	1.30	0.16	0.80	1.94	1.58	1.11

Zone 67	Zone 68	Zone 64	Zone 62	Zone 32	Zone 34 A	Zone 34 B	Zone 34 C	Zone 48
6.2	2.2	9.2	14.6	10.7	11.3	11.3	11.3	32.5
16.8	19.3	15.8	16	12.9	13.3	13.3	13.3	21.6
19.9	24.4	13.8	10.4	19.7	17.2	17.2	17.2	15.6
16.7	19.1	12.9	11.5	18.4	13.4	13.4	13.4	4.1
4.8	9	4.4	5.7	1.5	3.4	3.4	3.4	24.3
23.4	25.8	21.4	21.1	21.1	19.5	19.5	19.5	14.9
15.5	18	10.5	10.4	16	10.4	10.4	10.4	16
9.5	11.9	5.7	2.8	7.2	6.5	6.5	6.5	12.1
3.5	6.6	5.9	6	8	9	9	9	31.8
3.15	3.76	1.76	3.64	3.37	3.81	3.81	3.81	4.86
2.47	2.91	1.37	3.26	3.21	4.68	4.68	4.68	5.52
4.53	5.40	3.06	4.42	3.82	2.85	2.85	2.85	4.57
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
8.97	10.08	8.26	7.75	7.02	8.84	8.84	8.84	10.84
3.65	4.49	2.17	3.69	3.18	3.44	3.44	3.44	4.92
2.98	3.93	1.57	2.83	2.28	4.32	4.32	4.32	5.81
4.25	4.97	2.77	4.45	3.99	2.70	2.70	2.70	4.09
4.83	5.61	3.35	4.89	4.35	2.26	2.26	2.26	3.90
5.61	6.44	4.13	5.53	4.92	1.91	1.91	1.91	3.82
4.37	5.06	2.91	4.62	4.18	2.56	2.56	2.56	3.88
4.80	5.27	3.46	5.33	5.01	2.46	2.46	2.46	3.18

4.70	5.59	3.24	4.56	3.94	2.78	2.78	2.78	4.56
4.70	5.59	3.24	4.56	3.94	2.78	2.78	2.78	4.56
4.70	5.59	3.24	4.56	3.94	2.78	2.78	2.78	4.56
0.93	2.02	0.88	1.07	1.25	6.27	6.27	6.27	7.49
5.88	6.71	4.41	5.79	5.16	1.80	1.80	1.80	3.76
5.88	6.71	4.41	5.79	5.16	1.80	1.80	1.80	3.76
5.88	6.71	4.41	5.79	5.16	1.80	1.80	1.80	3.76
2.80	3.91	2.22	1.77	0.96	6.07	6.07	6.07	7.69
2.80	3.89	1.80	2.16	1.44	5.26	5.26	5.26	6.85
4.25	5.26	2.93	3.79	3.06	3.94	3.94	3.94	5.74
4.25	5.26	2.93	3.79	3.06	3.94	3.94	3.94	5.74
4.95	5.97	3.63	4.44	3.68	3.76	3.76	3.76	5.67
4.22	4.83	2.81	4.61	4.25	2.74	2.74	2.74	3.84
4.28	4.98	2.82	4.53	4.08	2.65	2.65	2.65	3.98
6.51	7.43	5.07	6.21	5.50	2.48	2.48	2.48	4.49
6.89	7.70	5.41	6.80	6.15	1.45	1.45	1.45	3.42
2.27	2.19	3.68	2.31	3.11	9.15	9.15	9.15	10.24
4.38	5.28	2.93	4.21	3.58	3.12	3.12	3.12	4.85
3.35	4.34	2.00	3.04	2.40	4.24	4.24	4.24	5.84
3.98	4.98	2.64	3.58	2.89	3.94	3.94	3.94	5.68
1.34	2.43	0.83	1.15	1.04	6.01	6.01	6.01	7.31
1.82	2.92	1.09	1.33	0.89	5.80	5.80	5.80	7.20
3.31	4.10	1.83	3.49	3.06	3.66	3.66	3.66	5.00
0.00	1.11	1.48	1.39	1.97	6.93	6.93	6.93	7.97
1.11	0.00	2.36	2.40	3.06	7.57	7.57	7.57	8.39
1.48	2.36	0.00	1.92	1.86	5.47	5.47	5.47	6.62
1.39	2.40	1.92	0.00	0.82	7.12	7.12	7.12	8.46
1.97	3.06	1.86	0.82	0.00	6.60	6.60	6.60	8.06
6.93	7.57	5.47	7.12	6.60	0.00	0.00	0.00	2.00
6.93	7.57	5.47	7.12	6.60	0.00	0.00	0.00	2.00
6.93	7.57	5.47	7.12	6.60	0.00	0.00	0.00	2.00
7.97	8.39	6.62	8.46	8.06	2.00	2.00	2.00	0.00
4.68	5.22	3.29	5.12	4.77	2.39	2.39	2.39	3.34
8.15	8.95	6.67	8.06	7.41	1.91	1.91	1.91	3.42
4.37	5.24	2.90	4.29	3.70	2.94	2.94	2.94	4.62
3.43	4.29	1.96	3.43	2.92	3.69	3.69	3.69	5.17
5.06	5.86	3.58	5.06	4.49	2.14	2.14	2.14	3.89
5.26	6.18	3.82	5.01	4.33	2.72	2.72	2.72	4.63
5.26	6.18	3.82	5.01	4.33	2.72	2.72	2.72	4.63
5.22	6.24	3.91	4.67	3.90	3.82	3.82	3.82	5.76
5.50	6.43	4.07	5.19	4.49	2.77	2.77	2.77	4.73
5.55	5.92	4.27	6.16	5.87	2.32	2.32	2.32	2.47
4.52	5.43	3.07	4.32	3.68	3.06	3.06	3.06	4.83
3.19	4.18	1.84	2.91	2.29	4.32	4.32	4.32	5.90

5.09	5.85	3.61	5.16	4.61	1.99	1.99	1.99	3.68
1.18	1.79	2.39	0.97	1.79	7.82	7.82	7.82	9.00
2.12	2.65	0.98	2.87	2.84	4.92	4.92	4.92	5.86
1.33	2.02	0.48	2.12	2.22	5.62	5.62	5.62	6.65
4.68	3.97	4.79	6.05	6.45	7.39	7.39	7.39	7.20
2.47	3.30	0.99	2.70	2.38	4.50	4.50	4.50	5.75
2.47	3.30	0.99	2.70	2.38	4.50	4.50	4.50	5.75
5.55	5.92	4.27	6.16	5.87	2.32	2.32	2.32	2.47
4.52	5.43	3.07	4.32	3.68	3.06	3.06	3.06	4.83
3.19	4.18	1.84	2.91	2.29	4.32	4.32	4.32	5.90
3.19	4.18	1.84	2.91	2.29	4.32	4.32	4.32	5.90
3.19	4.18	1.84	2.91	2.29	4.32	4.32	4.32	5.90
3.19	4.18	1.84	2.91	2.29	4.32	4.32	4.32	5.90

Zone 49	Zone 19	Zone 50	Zone 4	Zone 13	Zone 26 A	Zone 26 B	Zone 41	Zone 43
29.3	21.6	25.7	14.2	17.6	23	23	22.1	18.8
26.5	13.8	14.9	12.1	9.1	11.7	11.7	12.2	8.8
14.2	8.8	7.9	6.1	6	5.6	5.6	7.5	8.9
6.5	5.1	11.4	6.3	7.2	5	5	6.9	11.2
21.1	13.5	20.1	12.1	8.2	15.3	15.3	13.6	13.5
14.9	14	2.8	14.1	15.5	8.8	8.8	7.9	10
20.8	9.3	10.2	4.7	4.3	6.6	6.6	3.4	2.2
11.6	8.8	16.4	3.6	2.8	5.4	5.4	7.8	7.6
18.8	13.2	25.4	10	9.3	11.5	11.5	21.1	18.1
1.53	5.24	1.85	1.20	2.23	2.84	2.84	3.43	3.12
2.31	6.17	2.73	1.94	3.16	3.73	3.73	4.21	4.01
1.91	3.66	0.17	1.11	0.70	0.84	0.84	1.61	1.12
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
8.92	7.92	7.09	7.38	7.43	6.49	6.49	5.41	6.29
1.77	4.50	0.75	0.26	1.41	1.74	1.74	2.23	2.01
2.59	5.26	1.47	0.65	2.24	2.29	2.29	2.36	2.52
0.99	3.99	0.89	1.08	0.98	1.74	1.74	2.60	2.02
1.37	3.34	0.71	1.46	0.28	1.16	1.16	2.18	1.41
2.08	2.55	1.26	2.18	0.61	0.81	0.81	1.94	0.92
0.78	3.93	1.08	1.29	1.02	1.86	1.86	2.77	2.13

0.36	4.21	2.21	2.30	1.94	2.88	2.88	3.88	3.13
2.03	3.50	0.36	1.29	0.67	0.64	0.64	1.48	0.92
2.03	3.50	0.36	1.29	0.67	0.64	0.64	1.48	0.92
2.03	3.50	0.36	1.29	0.67	0.64	0.64	1.48	0.92
4.15	7.38	3.57	2.65	4.30	4.41	4.41	4.30	4.64
2.29	2.28	1.52	2.46	0.88	0.94	0.94	2.02	0.97
2.29	2.28	1.52	2.46	0.88	0.94	0.94	2.02	0.97
2.29	2.28	1.52	2.46	0.88	0.94	0.94	2.02	0.97
4.50	6.69	3.14	2.54	3.93	3.61	3.61	3.03	3.74
3.67	5.98	2.33	1.70	3.12	2.90	2.90	2.51	3.06
3.01	4.39	1.19	1.39	1.85	1.33	1.33	0.98	1.45
3.01	4.39	1.19	1.39	1.85	1.33	1.33	0.98	1.45
3.29	3.92	1.46	1.98	1.87	1.04	1.04	0.29	1.02
0.52	4.26	1.50	1.48	1.47	2.32	2.32	3.21	2.59
0.85	4.00	1.03	1.19	1.04	1.85	1.85	2.73	2.12
3.33	2.06	2.21	3.14	1.81	1.25	1.25	1.78	1.02
2.97	1.27	2.53	3.46	1.84	1.85	1.85	2.75	1.77
6.94	10.26	6.45	5.54	7.19	7.25	7.25	6.98	7.46
2.13	3.86	0.28	1.00	0.98	0.90	0.90	1.45	1.16
2.75	5.02	1.30	0.78	2.10	1.98	1.98	1.92	2.18
2.83	4.53	1.07	1.11	1.81	1.45	1.45	1.28	1.61
3.97	7.05	3.25	2.35	3.99	4.06	4.06	3.91	4.27
3.89	6.73	2.95	2.11	3.73	3.70	3.70	3.47	3.90
1.72	4.85	1.18	0.41	1.75	2.17	2.17	2.66	2.45
4.68	8.15	4.37	3.43	5.06	5.26	5.26	5.22	5.50
5.22	8.95	5.24	4.29	5.86	6.18	6.18	6.24	6.43
3.29	6.67	2.90	1.96	3.58	3.82	3.82	3.91	4.07
5.12	8.06	4.29	3.43	5.06	5.01	5.01	4.67	5.19
4.77	7.41	3.70	2.92	4.49	4.33	4.33	3.90	4.49
2.39	1.91	2.94	3.69	2.14	2.72	2.72	3.82	2.77
2.39	1.91	2.94	3.69	2.14	2.72	2.72	3.82	2.77
2.39	1.91	2.94	3.69	2.14	2.72	2.72	3.82	2.77
3.34	3.42	4.62	5.17	3.89	4.63	4.63	5.76	4.73
0.00	4.05	1.85	1.98	1.59	2.52	2.52	3.51	2.78
4.05	0.00	3.81	4.73	3.10	3.08	3.08	3.83	2.95
1.85	3.81	0.00	0.94	0.80	1.00	1.00	1.71	1.28
1.98	4.73	0.94	0.00	1.65	1.90	1.90	2.27	2.16
1.59	3.10	0.80	1.65	0.00	0.95	0.95	2.04	1.19
2.52	3.08	1.00	1.90	0.95	0.00	0.00	1.14	0.28
2.52	3.08	1.00	1.90	0.95	0.00	0.00	1.14	0.28
3.51	3.83	1.71	2.27	2.04	1.14	1.14	0.00	1.04
2.78	2.95	1.28	2.16	1.19	0.28	0.28	1.04	0.00
1.19	4.21	2.99	3.16	2.56	3.51	3.51	4.58	3.73
2.19	3.74	0.36	1.15	0.94	0.75	0.75	1.35	1.01

2.75	5.15	1.40	0.77	2.20	2.12	2.12	2.07	2.33
1.38	3.10	0.96	1.73	0.25	1.20	1.20	2.29	1.42
5.67	8.88	5.07	4.17	5.82	5.86	5.86	5.60	6.07
2.59	6.34	2.77	1.90	3.28	3.76	3.76	4.14	4.04
3.35	6.93	3.22	2.28	3.84	4.17	4.17	4.34	4.43
5.25	9.23	6.49	5.82	6.68	7.45	7.45	8.09	7.74
2.42	5.69	1.94	1.00	2.59	2.89	2.89	3.14	3.15
2.42	5.69	1.94	1.00	2.59	2.89	2.89	3.14	3.15
1.19	4.21	2.99	3.16	2.56	3.51	3.51	4.58	3.73
2.19	3.74	0.36	1.15	0.94	0.75	0.75	1.35	1.01
2.75	5.15	1.40	0.77	2.20	2.12	2.12	2.07	2.33
2.75	5.15	1.40	0.77	2.20	2.12	2.12	2.07	2.33
2.75	5.15	1.40	0.77	2.20	2.12	2.12	2.07	2.33
2.75	5.15	1.40	0.77	2.20	2.12	2.12	2.07	2.33

Zone 44	Zone 29	Zone 24	Zone 21	Zone 27	Zone 31	Zone 63	Zone 65	Zone 66 A
20.7	24.7	19.7	16	19.6	6.8	14.8	9.1	14.8
11.1	16.9	8.1	10.1	14	16.4	15.2	16.2	22.6
6.8	11.7	7.8	10	5.7	19.6	11.5	13.3	20.8
8.3	2.2	8.4	8.6	4	17.1	11	13.2	21
15.4	16.4	11.6	7.8	12.2	5.1	10.4	8.5	17.8
8.5	12.3	11.1	15.2	8.8	23	19.5	21.7	29.5
4.2	12.1	2.1	5.5	9.2	15.2	12.5	10.9	18.7
10.9	6.8	5.7	3.2	6.2	9.7	6.3	6	16
20.1	14.1	19	7.4	12.9	5.9	7.2	3.4	11.4
2.52	2.17	1.81	2.16	4.15	1.11	1.83	4.66	1.00
3.08	3.03	2.33	3.10	3.58	0.39	1.18	3.91	1.20
3.02	0.29	1.52	0.90	5.22	2.94	3.38	6.63	2.11
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
9.99	6.73	6.81	7.68	8.63	8.91	8.75	13.00	7.92
2.96	1.01	0.99	1.48	4.42	2.03	2.47	5.86	1.20
3.76	1.55	0.33	2.34	3.61	1.84	1.98	5.91	0.82
2.17	1.25	1.83	0.90	5.12	2.35	2.97	5.73	1.80
2.40	0.96	2.07	0.27	5.63	3.02	3.60	6.41	2.37
2.89	1.24	2.63	0.72	6.33	3.88	4.42	7.25	3.16

1.95	1.43	2.05	0.89	5.27	2.42	3.08	5.66	1.95
0.87	2.56	3.07	1.71	5.83	2.69	3.47	5.03	2.64
3.12	0.27	1.65	0.90	5.37	3.13	3.57	6.82	2.29
3.12	0.27	1.65	0.90	5.37	3.13	3.57	6.82	2.29
3.12	0.27	1.65	0.90	5.37	3.13	3.57	6.82	2.29
5.14	3.68	2.31	4.36	1.54	1.81	1.06	5.19	1.77
3.02	1.48	2.88	0.97	6.59	4.16	4.69	7.49	3.43
3.02	1.48	2.88	0.97	6.59	4.16	4.69	7.49	3.43
3.02	1.48	2.88	0.97	6.59	4.16	4.69	7.49	3.43
5.67	3.04	1.79	4.09	2.74	3.09	2.68	7.00	2.34
4.84	2.27	0.95	3.27	3.08	2.50	2.28	6.55	1.62
4.17	0.92	1.09	2.07	4.69	3.19	3.36	7.20	2.18
4.17	0.92	1.09	2.07	4.69	3.19	3.36	7.20	2.18
4.39	1.11	1.79	2.12	5.36	3.84	4.06	7.80	2.85
1.68	1.86	2.25	1.32	5.19	2.18	2.90	5.22	1.91
2.03	1.39	1.95	0.94	5.18	2.35	2.99	5.64	1.86
4.06	2.00	3.35	1.97	7.09	4.98	5.42	8.50	4.14
3.40	2.48	3.89	1.86	7.61	5.11	5.68	8.22	4.43
7.81	6.54	5.14	7.25	1.39	4.38	3.59	6.05	4.65
3.26	0.15	1.30	1.17	5.03	2.89	3.28	6.69	2.00
3.93	1.28	0.16	2.25	3.89	2.30	2.42	6.36	1.28
4.00	0.88	0.80	2.01	4.47	2.88	3.06	6.90	1.87
5.01	3.33	1.94	4.07	1.83	1.81	1.18	5.46	1.55
4.99	2.99	1.58	3.83	2.17	2.02	1.53	5.85	1.49
2.88	1.45	1.11	1.77	4.15	1.59	2.08	5.43	0.85
5.55	4.52	3.19	5.09	1.18	2.12	1.33	4.68	2.47
5.92	5.43	4.18	5.85	1.79	2.65	2.02	3.97	3.30
4.27	3.07	1.84	3.61	2.39	0.98	0.48	4.79	0.99
6.16	4.32	2.91	5.16	0.97	2.87	2.12	6.05	2.70
5.87	3.68	2.29	4.61	1.79	2.84	2.22	6.45	2.38
2.32	3.06	4.32	1.99	7.82	4.92	5.62	7.39	4.50
2.32	3.06	4.32	1.99	7.82	4.92	5.62	7.39	4.50
2.32	3.06	4.32	1.99	7.82	4.92	5.62	7.39	4.50
2.47	4.83	5.90	3.68	9.00	5.86	6.65	7.20	5.75
1.19	2.19	2.75	1.38	5.67	2.59	3.35	5.25	2.42
4.21	3.74	5.15	3.10	8.88	6.34	6.93	9.23	5.69
2.99	0.36	1.40	0.96	5.07	2.77	3.22	6.49	1.94
3.16	1.15	0.77	1.73	4.17	1.90	2.28	5.82	1.00
2.56	0.94	2.20	0.25	5.82	3.28	3.84	6.68	2.59
3.51	0.75	2.12	1.20	5.86	3.76	4.17	7.45	2.89
3.51	0.75	2.12	1.20	5.86	3.76	4.17	7.45	2.89
4.58	1.35	2.07	2.29	5.60	4.14	4.34	8.09	3.14
3.73	1.01	2.33	1.42	6.07	4.04	4.43	7.74	3.15
0.00	3.31	3.94	2.31	6.62	3.43	4.23	5.10	3.49

3.31	0.00	1.41	1.15	5.15	3.03	3.42	6.82	2.14
3.94	1.41	0.00	2.33	3.75	2.16	2.27	6.24	1.15
2.31	1.15	2.33	0.00	5.89	3.25	3.84	6.53	2.62
6.62	5.15	3.75	5.89	0.00	3.20	2.40	5.72	3.32
3.43	3.03	2.16	3.25	3.20	0.00	0.80	4.09	1.02
4.23	3.42	2.27	3.84	2.40	0.80	0.00	4.32	1.28
5.10	6.82	6.24	6.53	5.72	4.09	4.32	0.00	5.10
3.49	2.14	1.15	2.62	3.32	1.02	1.28	5.10	0.00
3.49	2.14	1.15	2.62	3.32	1.02	1.28	5.10	0.00
0.00	3.31	3.94	2.31	6.62	3.43	4.23	5.10	3.49
3.31	0.00	1.41	1.15	5.15	3.03	3.42	6.82	2.14
3.94	1.41	0.00	2.33	3.75	2.16	2.27	6.24	1.15
3.94	1.41	0.00	2.33	3.75	2.16	2.27	6.24	1.15
3.94	1.41	0.00	2.33	3.75	2.16	2.27	6.24	1.15
3.94	1.41	0.00	2.33	3.75	2.16	2.27	6.24	1.15

Zone 66 B	Zone 20	Zone 69	Zone 70 A	Zone 70 B	Zone 70 C	Zone 70 D
14.8	14.5	6.8	14.8	14.8	14.8	14.8
22.6	13.1	16.4	15.2	15.2	15.2	15.2
20.8	11.4	19.6	11.5	11.5	11.5	11.5
21	10.6	17.1	11	11	11	11
17.8	5	5.1	10.4	10.4	10.4	10.4
29.5	16.6	23	19.5	19.5	19.5	19.5
18.7	7.8	15.2	12.5	12.5	12.5	12.5
16	3.4	9.7	6.3	6.3	6.3	6.3
11.4	7.8	5.9	7.2	7.2	7.2	7.2
1.00	4.15	1.11	1.83	1.83	1.83	1.83
1.20	3.58	0.39	1.18	1.18	1.18	1.18
2.11	5.22	2.94	3.38	3.38	3.38	3.38
7.92	8.63	8.91	8.75	8.75	8.75	8.75
7.92	8.63	8.91	8.75	8.75	8.75	8.75
7.92	8.63	8.91	8.75	8.75	8.75	8.75
7.92	8.63	8.91	8.75	8.75	8.75	8.75
7.92	8.63	8.91	8.75	8.75	8.75	8.75
7.92	8.63	8.91	8.75	8.75	8.75	8.75
7.92	8.63	8.91	8.75	8.75	8.75	8.75
7.92	8.63	8.91	8.75	8.75	8.75	8.75
7.92	8.63	8.91	8.75	8.75	8.75	8.75
7.92	8.63	8.91	8.75	8.75	8.75	8.75
1.20	4.42	2.03	2.47	2.47	2.47	2.47
0.82	3.61	1.84	1.98	1.98	1.98	1.98
1.80	5.12	2.35	2.97	2.97	2.97	2.97
2.37	5.63	3.02	3.60	3.60	3.60	3.60

3.16	6.33	3.88	4.42	4.42	4.42	4.42
1.95	5.27	2.42	3.08	3.08	3.08	3.08
2.64	5.83	2.69	3.47	3.47	3.47	3.47
2.29	5.37	3.13	3.57	3.57	3.57	3.57
2.29	5.37	3.13	3.57	3.57	3.57	3.57
2.29	5.37	3.13	3.57	3.57	3.57	3.57
1.77	1.54	1.81	1.06	1.06	1.06	1.06
3.43	6.59	4.16	4.69	4.69	4.69	4.69
3.43	6.59	4.16	4.69	4.69	4.69	4.69
3.43	6.59	4.16	4.69	4.69	4.69	4.69
2.34	2.74	3.09	2.68	2.68	2.68	2.68
1.62	3.08	2.50	2.28	2.28	2.28	2.28
2.18	4.69	3.19	3.36	3.36	3.36	3.36
2.18	4.69	3.19	3.36	3.36	3.36	3.36
2.85	5.36	3.84	4.06	4.06	4.06	4.06
1.91	5.19	2.18	2.90	2.90	2.90	2.90
1.86	5.18	2.35	2.99	2.99	2.99	2.99
4.14	7.09	4.98	5.42	5.42	5.42	5.42
4.43	7.61	5.11	5.68	5.68	5.68	5.68
4.65	1.39	4.38	3.59	3.59	3.59	3.59
2.00	5.03	2.89	3.28	3.28	3.28	3.28
1.28	3.89	2.30	2.42	2.42	2.42	2.42
1.87	4.47	2.88	3.06	3.06	3.06	3.06
1.55	1.83	1.81	1.18	1.18	1.18	1.18
1.49	2.17	2.02	1.53	1.53	1.53	1.53
0.85	4.15	1.59	2.08	2.08	2.08	2.08
2.47	1.18	2.12	1.33	1.33	1.33	1.33
3.30	1.79	2.65	2.02	2.02	2.02	2.02
0.99	2.39	0.98	0.48	0.48	0.48	0.48
2.70	0.97	2.87	2.12	2.12	2.12	2.12
2.38	1.79	2.84	2.22	2.22	2.22	2.22
4.50	7.82	4.92	5.62	5.62	5.62	5.62
4.50	7.82	4.92	5.62	5.62	5.62	5.62
4.50	7.82	4.92	5.62	5.62	5.62	5.62
5.75	9.00	5.86	6.65	6.65	6.65	6.65
2.42	5.67	2.59	3.35	3.35	3.35	3.35
5.69	8.88	6.34	6.93	6.93	6.93	6.93
1.94	5.07	2.77	3.22	3.22	3.22	3.22
1.00	4.17	1.90	2.28	2.28	2.28	2.28
2.59	5.82	3.28	3.84	3.84	3.84	3.84
2.89	5.86	3.76	4.17	4.17	4.17	4.17
2.89	5.86	3.76	4.17	4.17	4.17	4.17
3.14	5.60	4.14	4.34	4.34	4.34	4.34
3.15	6.07	4.04	4.43	4.43	4.43	4.43

3.49	6.62	3.43	4.23	4.23	4.23	4.23
2.14	5.15	3.03	3.42	3.42	3.42	3.42
1.15	3.75	2.16	2.27	2.27	2.27	2.27
2.62	5.89	3.25	3.84	3.84	3.84	3.84
3.32	0.00	3.20	2.40	2.40	2.40	2.40
1.02	3.20	0.00	0.80	0.80	0.80	0.80
1.28	2.40	0.80	0.00	0.00	0.00	0.00
5.10	5.72	4.09	4.32	4.32	4.32	4.32
0.00	3.32	1.02	1.28	1.28	1.28	1.28
0.00	3.32	1.02	1.28	1.28	1.28	1.28
3.49	6.62	3.43	4.23	4.23	4.23	4.23
2.14	5.15	3.03	3.42	3.42	3.42	3.42
1.15	3.75	2.16	2.27	2.27	2.27	2.27
1.15	3.75	2.16	2.27	2.27	2.27	2.27
1.15	3.75	2.16	2.27	2.27	2.27	2.27
1.15	3.75	2.16	2.27	2.27	2.27	2.27

APPENDIX C : EXISTING HEALTH CENTERS DATA

SN.	Health Center	Capacity Per Day	Capacity Per Year
1	Airport	500	130,000
2	Madinat Khalifa	500	130,000
3	Al Khatab	750	195,000
4	Qatar Univ	1000	260,000
5	Rawdat	750	195,000
6	Al Thumama	750	195,000
7	Um Ghwalina	500	130,000
8	Al Waab	750	195,000
9	West Bay	1000	260,000

Number of Registered Pations				
2017	2018	2019	2020	2021
64,486	68,253	68,772	69,372	70,767
66,003	63,954	67,180	67,978	69,208
60,344	58,143	58,811	56,948	57,284
	26,390	23,144	43,901	61,809
77,954	90,504	106,419	126,356	128,009
24,870	36,488	51,281	65,706	78,572
49,606	53,114	54,056	53,535	52,321
	18,181	39,303	50,845	66,553
109,715	99,381	94,552	90,493	89,135

Number of Visits				
2017	2018	2019	2020	2021
532,999	489,156	425,730	359,726	671,101
545,537	458,345	415,875	352,497	656,316
498,764	416,699	364,067	295,302	543,238
0	189,132	143,272	227,647	586,150
644,316	648,624	658,782	655,214	1,213,941
205,559	261,502	317,453	340,716	745,118
410,011	380,657	334,631	277,604	496,173
0	130,300	243,304	263,655	631,138
906,832	712,244	585,320	469,248	845,289

No Show %				
2017	2018	2019	2020	2021
36.00%	27.80%	11.79%	17.81%	36.90%
37.00%	21.26%	20.78%	11.60%	33.60%

41.00%	23.70%	32.90%	36.58%	35.00%
	16.80%	28.00%	11.78%	37.89%
21.00%	41.60%	29.70%	36.84%	36.99%
25.00%	19.80%	19.78%	16.95%	27.89%
18.00%	18.50%	16.90%	17.82%	49.22%
	15.98%	25.79%	17.22%	39.97%
44.00%	41.58%	59.67%	9.80%	29.86%

APPENDIX D : CODE FOR OBJECTIVE FUNCTION NO. 1

```
/*********************************************
 * OPL 22.1.1.0 Model
 * Author: Ahmed Mashhadani
 * Creation Date: Mar 4, 2024 at 3:24:02 PM
 *********************************************/



int p = 87;  // Number of facilities to be located
int n = 78;  // Number of demand points
float u_max= 0.9;
float u_min= 0.4;


range HealthCenters = 1..p;
range DemandPoints = 1..n;
range Capacity = 1..p;
float HealthCentersCapacityPerYear[Capacity];
float demandPerYear[DemandPoints];
float HealthCentersCapacity[Capacity] = ...; // Fill in your
HealthCentersCapacity array here
float distance[HealthCenters][DemandPoints] = ...; // Fill in your distance
matrix here

// Distance matrix between facilities and demand points
float demand[DemandPoints] = ...; // Fill in your demand array here
float WeightedDistance[HealthCenters][DemandPoints];  // Result matrix
float U_Max_HealthCentersCapacityPerYear[Capacity];
float U_Min_HealthCentersCapacityPerYear[Capacity];


execute {
    writeln("HealthCentersCapacityPerYear:");
    for (var j in Capacity) {
        HealthCentersCapacityPerYear[j] = 240 * HealthCentersCapacity[j];
        write(HealthCentersCapacityPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("demandPerYear:");
    for (var j in DemandPoints) {
        demandPerYear[j] = 3.5 * demand[j];
        write(demandPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("WeightedDistance:");
    for (var i in HealthCenters) {
        for (var j in DemandPoints) {
            WeightedDistance[i][j] = distance[i][j] * demand[j];
            write(WeightedDistance[i][j], "\t");
        }
        writeln();
```

```
    }
}


//upper limit

execute {
    writeln("U_Max_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Max_HealthCentersCapacityPerYear[j] = u_max*240 *
HealthCentersCapacity[j];
            write(U_Max_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }


//lower limit

execute {
    writeln("U_Min_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Min_HealthCentersCapacityPerYear[j] = u_min*240 *
HealthCentersCapacity[j];
            write(U_Min_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }



dvar boolean x[HealthCenters][DemandPoints];  // Binary decision variable
indicating if facility i serves demand point j
dvar boolean y[HealthCenters];  // Binary decision variable indicating if
facility i is located

minimize sum(i in HealthCenters, j in DemandPoints) WeightedDistance[i][j]
* x[i][j];  // Objective function to minimize total distance

subject to {
 // [1] Constraint: Each demand point must be served by exactly one
facility
    forall(j in DemandPoints )
        sum(i in HealthCenters) x[i][j] == 1;

    // [2] Constraint: Facility i can only serve demand points if it is
located
    forall(i in HealthCenters, j in DemandPoints)
        x[i][j] <= y[i];

    // [3] Constraint: The total number of facilities to be located is
equal to p
    sum(i in HealthCenters) y[i] <= 18;

    // [4] The total demand assigned to each facility must not exceed its
capacity
```

```
    forall(i in HealthCenters)
        sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
HealthCentersCapacityPerYear[i] * y[i];


             // [5] The total demand assigned to each facility must not
exceed its capacity
  forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
U_Max_HealthCentersCapacityPerYear[i]*y[i];

     forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] >=
U_Min_HealthCentersCapacityPerYear[i]*y[i];

    // [6] Current Health Centers will remain open

y[1]==1;y[2]==1;y[3]==1;y[4]==1;y[5]==1;y[6]==1;y[7]==1;y[8]==1;y[9]==1;

   // This ensures y[i] is binary (0 or 1)
    forall(i in HealthCenters)
       y[i] <= 1;


}

execute {
    writeln("Objective value: ", cplex.getObjValue());
    for (var i in HealthCenters) {
        if (y[i] == 1) {
            writeln("HealthCenters ", i, " is located.");
            for (var j in DemandPoints) {
                if (x[i][j] == 1)
                    writeln("  HealthCenters ", i, " serves demand point ",
j);
            }
        }
    }}
```

APPENDIX E : CODE FOR OBJECTIVE FUNCTION NO. 2

```
/*********************************************
 * OPL 22.1.1.0 Model
 * Author: Ahmed Mashhadani
 * Creation Date: Mar 5, 2024 at 2:56:09 PM
 *********************************************/

int p = 87;  // Number of facilities to be located
int n = 78;  // Number of demand points
float u_max= 0.9;
float u_min= 0.4;

//float AverageDistance;
range HealthCenters = 1..p;
range DemandPoints = 1..n;
range Capacity = 1..p;
float HealthCentersCapacity[Capacity] = ...; // Fill in your
HealthCentersCapacity array here
float HealthCentersCapacityPerYear[Capacity];
float demandPerYear[DemandPoints];

float distance[HealthCenters][DemandPoints] = ...; // Fill in your distance
matrix here

float demand[DemandPoints] = ...; // Fill in your demand array here
float WeightedDistance[HealthCenters][DemandPoints];  // Result matrix
float U_Max_HealthCentersCapacityPerYear[Capacity];
float U_Min_HealthCentersCapacityPerYear[Capacity];



execute {
    writeln("HealthCentersCapacityPerYear:");
    for (var j in Capacity) {
        HealthCentersCapacityPerYear[j] = 240 * HealthCentersCapacity[j];
        write(HealthCentersCapacityPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("demandPerYear:");
    for (var j in DemandPoints) {
        demandPerYear[j] = 3.5 * demand[j];
        write(demandPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("WeightedDistance:");
    for (var i in HealthCenters) {
        for (var j in DemandPoints) {
            WeightedDistance[i][j] = distance[i][j] * demand[j];
            write(WeightedDistance[i][j], "\t");
        }
        writeln();
    }
```

```
}

//upper limit

execute {
    writeln("U_Max_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Max_HealthCentersCapacityPerYear[j] = u_max*
HealthCentersCapacityPerYear[j];
            write(U_Max_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }


//lower limit

execute {
    writeln("U_Min_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Min_HealthCentersCapacityPerYear[j] =
u_min*HealthCentersCapacityPerYear[j];
            write(U_Min_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }



dvar boolean x[HealthCenters][DemandPoints];  // Binary decision variable
indicating if facility i serves demand point j
dvar boolean y[HealthCenters];  // Binary decision variable indicating if
facility i is located



minimize
max (i in HealthCenters, j in DemandPoints)
distance[i][j]*x[i][j];
subject to {



    // [1] Constraint: Each demand point must be served by exactly one
facility
      forall(j in DemandPoints )
        sum(i in HealthCenters) x[i][j] == 1;

    // [2] Constraint: Facility i can only serve demand points if it is
located
    forall(i in HealthCenters, j in DemandPoints)
        x[i][j] <= y[i];

    // [3] Constraint: The total number of facilities to be located is
equal to p
    sum(i in HealthCenters) y[i] == 15;
```

```
 // [4] The total demand assigned to each facility must not exceed its
capacity
    forall(i in HealthCenters)
        sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
HealthCentersCapacityPerYear[i]*y[i];


            // [6] Current Health Centers will remain open

y[1]==1;y[2]==1;y[3]==1;y[4]==1;y[5]==1;y[6]==1;y[7]==1;y[8]==1;y[9]==1;


    // [6] Current Health Centers will remain open
    forall(i in HealthCenters)
        y[i] <= 1; // This ensures y[i] is binary (0 or 1)


     // [5] The total demand assigned to each facility must not exceed its
capacity
  forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
U_Max_HealthCentersCapacityPerYear[i]*y[i];

     forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] >=
U_Min_HealthCentersCapacityPerYear[i]*y[i];
}

execute {
    writeln("Objective value: ", cplex.getObjValue());
    for (var i in HealthCenters) {
        if (y[i] == 1) {
            writeln("HealthCenters ", i, " is located.");
            for (var j in DemandPoints) {
                if (x[i][j] == 1)
                    writeln("  HealthCenters ", i, " serves demand point ",
j);
            }
        }
    }}
```

APPENDIX F : CODE FOR OBJECTIVE FUNCTION NO. 3

```
/*********************************************
 * OPL 22.1.1.0 Model
 * Author: Ahmed Mashhadani
 * Creation Date: Mar 10, 2024 at 3:52:17 PM
 *********************************************/

int p = 87;  // Number of facilities to be located
int n = 78;  // Number of demand points
float u_max= 0.9;
float u_min= 0.4;


range HealthCenters = 1..p;
range DemandPoints = 1..n;
range Capacity = 1..p;
float HealthCentersCapacity[Capacity] = ...; // Fill in your
HealthCentersCapacity array here
float HealthCentersCapacityPerYear[Capacity];
float demandPerYear[DemandPoints];

float distance[HealthCenters][DemandPoints] = ...; // Fill in your distance
matrix here

float demand[DemandPoints] = ...; // Fill in your demand array here
float WeightedDistance[HealthCenters][DemandPoints];  // Result matrix
float U_Max_HealthCentersCapacityPerYear[Capacity];
float U_Min_HealthCentersCapacityPerYear[Capacity];


execute {
    writeln("HealthCentersCapacityPerYear:");
    for (var j in Capacity) {
        HealthCentersCapacityPerYear[j] = 240 * HealthCentersCapacity[j];
        write(HealthCentersCapacityPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("demandPerYear:");
    for (var j in DemandPoints) {
        demandPerYear[j] = 3.5 * demand[j];
        write(demandPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("WeightedDistance:");
    for (var i in HealthCenters) {
        for (var j in DemandPoints) {
            WeightedDistance[i][j] = distance[i][j] * demand[j];
            write(WeightedDistance[i][j], "\t");
        }
        writeln();
    }
}
```

```
//upper limit

execute {
    writeln("U_Max_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Max_HealthCentersCapacityPerYear[j] = u_max*
HealthCentersCapacityPerYear[j];
            write(U_Max_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }


//lower limit

execute {
    writeln("U_Min_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Min_HealthCentersCapacityPerYear[j] =
u_min*HealthCentersCapacityPerYear[j];
            write(U_Min_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }



dvar boolean x[HealthCenters][DemandPoints];  // Binary decision variable
indicating if facility i serves demand point j
dvar boolean y[HealthCenters];  // Binary decision variable indicating if
facility i is located
dvar float u[HealthCenters];


minimize sum(i in HealthCenters) (5.51330629*u[i]-1.12888558*y[i]);  //
Objective function to minimize total distance

subject to {


  forall(i in HealthCenters, j in DemandPoints){
   u[i]== (sum (j in DemandPoints)demand[j]*x[i][j]) /
HealthCentersCapacityPerYear[i];
    }

    // [1] Constraint: Each demand point must be served by exactly one
facility
      forall(j in DemandPoints )
        sum(i in HealthCenters) x[i][j] == 1;
     // [2] Constraint: Facility i can only serve demand points if it is
located
    forall(i in HealthCenters, j in DemandPoints)
        x[i][j] <= y[i];

    // [3] Constraint: The total number of facilities to be located is
equal to p
```

```
    sum(i in HealthCenters) y[i] <= 16;

    forall (i in HealthCenters)
      u[i]<=1;

      forall (i in HealthCenters)
      u[i]>=0;

 // [4] The total demand assigned to each facility must not exceed its
capacity
   forall(i in HealthCenters)
       sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
HealthCentersCapacityPerYear[i]*y[i];


            // [6] Current Health Centers will remain open

y[1]==1;y[2]==1;y[3]==1;y[4]==1;y[5]==1;y[6]==1;y[7]==1;y[8]==1;y[9]==1;


    // [6] Current Health Centers will remain open
    forall(i in HealthCenters)
        y[i] <= 1; // This ensures y[i] is binary (0 or 1)


  //[5] The total demand assigned to each facility must not exceed its
capacity
  forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
U_Max_HealthCentersCapacityPerYear[i]*y[i];

     forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] >=
U_Min_HealthCentersCapacityPerYear[i]*y[i];


}

execute {
    writeln("Objective value: ", cplex.getObjValue());
    for (var i in HealthCenters) {
        if (y[i] == 1) {
            writeln("HealthCenters ", i, " is located.");
            for (var j in DemandPoints) {
                if (x[i][j] == 1)
                    writeln("  HealthCenters ", i, " serves demand point ",
j);
            }
        }
  }
}
```

APPENDIX G : CODE FOR INTEGRATED MODEL

```
/*********************************************
 * OPL 22.1.1.0 Model
 * Author: Ahmed Mashhadani
```

```
 * Creation Date: Mar 5, 2024 at 2:56:09 PM
 *********************************************/

int p = 87;  // Number of facilities to be located
int n = 78;  // Number of demand points
float u_max= 0.9;
float u_min= 0.4;

//float AverageDistance;
range HealthCenters = 1..p;
range DemandPoints = 1..n;
range Capacity = 1..p;
float HealthCentersCapacity[Capacity] = ...; // Fill in your
HealthCentersCapacity array here
float HealthCentersCapacityPerYear[Capacity];
float demandPerYear[DemandPoints];

float distance[HealthCenters][DemandPoints] = ...; // Fill in your distance
matrix here

float demand[DemandPoints] = ...; // Fill in your demand array here
float WeightedDistance[HealthCenters][DemandPoints];  // Result matrix
float U_Max_HealthCentersCapacityPerYear[Capacity];
float U_Min_HealthCentersCapacityPerYear[Capacity];



execute {
    writeln("HealthCentersCapacityPerYear:");
    for (var j in Capacity) {
        HealthCentersCapacityPerYear[j] = 240 * HealthCentersCapacity[j];
        write(HealthCentersCapacityPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("demandPerYear:");
    for (var j in DemandPoints) {
        demandPerYear[j] = 3.5 * demand[j];
        write(demandPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("WeightedDistance:");
    for (var i in HealthCenters) {
        for (var j in DemandPoints) {
            WeightedDistance[i][j] = distance[i][j] * demand[j];
            write(WeightedDistance[i][j], "\t");
        }
        writeln();
    }
}

//upper limit

execute {
```

```
    writeln("U_Max_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Max_HealthCentersCapacityPerYear[j] = u_max*
HealthCentersCapacityPerYear[j];
            write(U_Max_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }


//lower limit

execute {
    writeln("U_Min_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Min_HealthCentersCapacityPerYear[j] =
u_min*HealthCentersCapacityPerYear[j];
            write(U_Min_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }



dvar boolean x[HealthCenters][DemandPoints];  // Binary decision variable
indicating if facility i serves demand point j
dvar boolean y[HealthCenters];  // Binary decision variable indicating if
facility i is located



minimize
max (i in HealthCenters, j in DemandPoints)
distance[i][j]*x[i][j];
subject to {



    // [1] Constraint: Each demand point must be served by exactly one
facility
      forall(j in DemandPoints )
        sum(i in HealthCenters) x[i][j] == 1;

    // [2] Constraint: Facility i can only serve demand points if it is
located
    forall(i in HealthCenters, j in DemandPoints)
        x[i][j] <= y[i];

    // [3] Constraint: The total number of facilities to be located is
equal to p
    sum(i in HealthCenters) y[i] == 15;


   // [4] The total demand assigned to each facility must not exceed its
capacity
    forall(i in HealthCenters)
```

```
        sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
HealthCentersCapacityPerYear[i]*y[i];


            // [6] Current Health Centers will remain open

y[1]==1;y[2]==1;y[3]==1;y[4]==1;y[5]==1;y[6]==1;y[7]==1;y[8]==1;y[9]==1;


    // [6] Current Health Centers will remain open
    forall(i in HealthCenters)
        y[i] <= 1; // This ensures y[i] is binary (0 or 1)

    // Constraints specific to your problem (insure Z1 PMedian >> Z3 No
show >> Z2 P center), if any
    forall (i in HealthCenters, j in DemandPoints)   //Z1
    sum(i in HealthCenters, j in DemandPoints) WeightedDistance[i][j]*
x[i][j] <= (1.3*8131122.54999999);

    forall(i in HealthCenters, j in DemandPoints){
      5.51330629*((sum (j in DemandPoints)demand[j]*x[i][j]) /
HealthCentersCapacityPerYear[i])-1.12888558*y[i]<=56.311;
    }




 // [5] The total demand assigned to each facility must not exceed its
capacity
  forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
U_Max_HealthCentersCapacityPerYear[i]*y[i];

     forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] >=
U_Min_HealthCentersCapacityPerYear[i]*y[i];




}

execute {
    writeln("Objective value: ", cplex.getObjValue());
    for (var i in HealthCenters) {
        if (y[i] == 1) {
            writeln("HealthCenters ", i, " is located.");
            for (var j in DemandPoints) {
                if (x[i][j] == 1)
                    writeln("  HealthCenters ", i, " serves demand point ",
j);
            }
        }
    }}
/*********************************************
 * OPL 22.1.1.0 Model
 * Author: Ahmed Mashhadani
 * Creation Date: Mar 10, 2024 at 3:52:17 PM
 *********************************************/
```

```
int p = 87;  // Number of facilities to be located
int n = 78;  // Number of demand points
float u_max= 0.9;
float u_min= 0.4;


range HealthCenters = 1..p;
range DemandPoints = 1..n;
range Capacity = 1..p;
float HealthCentersCapacity[Capacity] = ...; // Fill in your
HealthCentersCapacity array here
float HealthCentersCapacityPerYear[Capacity];
float demandPerYear[DemandPoints];

float distance[HealthCenters][DemandPoints] = ...; // Fill in your distance
matrix here

float demand[DemandPoints] = ...; // Fill in your demand array here
float WeightedDistance[HealthCenters][DemandPoints];  // Result matrix
float U_Max_HealthCentersCapacityPerYear[Capacity];
float U_Min_HealthCentersCapacityPerYear[Capacity];


execute {
    writeln("HealthCentersCapacityPerYear:");
    for (var j in Capacity) {
        HealthCentersCapacityPerYear[j] = 240 * HealthCentersCapacity[j];
        write(HealthCentersCapacityPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("demandPerYear:");
    for (var j in DemandPoints) {
        demandPerYear[j] = 3.5 * demand[j];
        write(demandPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("WeightedDistance:");
    for (var i in HealthCenters) {
        for (var j in DemandPoints) {
            WeightedDistance[i][j] = distance[i][j] * demand[j];
            write(WeightedDistance[i][j], "\t");
        }
        writeln();
    }
}

//upper limit

execute {
    writeln("U_Max_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
```

```
            U_Max_HealthCentersCapacityPerYear[j] = u_max*
HealthCentersCapacityPerYear[j];
            write(U_Max_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }


//lower limit

execute {
    writeln("U_Min_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Min_HealthCentersCapacityPerYear[j] =
u_min*HealthCentersCapacityPerYear[j];
            write(U_Min_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }



dvar boolean x[HealthCenters][DemandPoints];  // Binary decision variable
indicating if facility i serves demand point j
dvar boolean y[HealthCenters];  // Binary decision variable indicating if
facility i is located
dvar float u[HealthCenters];


minimize sum(i in HealthCenters) (5.51330629*u[i]-1.12888558*y[i]);  //
Objective function to minimize total distance

subject to {


  forall(i in HealthCenters, j in DemandPoints){
   u[i]== (sum (j in DemandPoints)demand[j]*x[i][j]) /
HealthCentersCapacityPerYear[i];
    }

    // [1] Constraint: Each demand point must be served by exactly one
facility
      forall(j in DemandPoints )
        sum(i in HealthCenters) x[i][j] == 1;
     // [2] Constraint: Facility i can only serve demand points if it is
located
    forall(i in HealthCenters, j in DemandPoints)
        x[i][j] <= y[i];

    // [3] Constraint: The total number of facilities to be located is
equal to p
    sum(i in HealthCenters) y[i] <= 16;

    forall (i in HealthCenters)
      u[i]<=1;

      forall (i in HealthCenters)
      u[i]>=0;
```

```
 // [4] The total demand assigned to each facility must not exceed its
capacity
   forall(i in HealthCenters)
       sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
HealthCentersCapacityPerYear[i]*y[i];


            // [6] Current Health Centers will remain open

y[1]==1;y[2]==1;y[3]==1;y[4]==1;y[5]==1;y[6]==1;y[7]==1;y[8]==1;y[9]==1;


    // [6] Current Health Centers will remain open
    forall(i in HealthCenters)
        y[i] <= 1; // This ensures y[i] is binary (0 or 1)

    // Constraints specific to your problem (insure Z1 PMedian >> Z3 No
show >> Z2 P center), if any
forall (i in HealthCenters, j in DemandPoints)
    sum(i in HealthCenters, j in DemandPoints) WeightedDistance[i][j]*
x[i][j] <= (1.5*6916820.87);



  //[5] The total demand assigned to each facility must not exceed its
capacity
  forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] <=
U_Max_HealthCentersCapacityPerYear[i]*y[i];

     forall(i in HealthCenters)
    sum(j in DemandPoints) demandPerYear[j] * x[i][j] >=
U_Min_HealthCentersCapacityPerYear[i]*y[i];


}
execute {
    writeln("Objective value: ", cplex.getObjValue());
    for (var i in HealthCenters) {
        if (y[i] == 1) {
            writeln("HealthCenters ", i, " is located.");
            for (var j in DemandPoints) {
                if (x[i][j] == 1)
                    writeln("  HealthCenters ", i, " serves demand point ",
j);
            }
        }
  }
}
```

APPENDIX H : CODE FOR OBJECTIVE FUNCTION NO. 4

```
/*********************************************
 * OPL 22.1.1.0 Model
 * Author: Ahmed Mashhadani
 * Creation Date: Mar 6, 2024 at 10:07:50 PM
 *********************************************/


int p = 87;  // Number of facilities to be located
int n = 78;  // Number of demand points
int T = 11;  // Number of intervals
float u_max= 0.95;
float u_min= 0.4;
int AdditionalCenters=3;

range HealthCenters = 1..p;
range DemandPoints = 1..n;
range time=1..T;
range Capacity=1..p;

float distance[HealthCenters][DemandPoints] = ...;

float HealthCentersCapacity[Capacity] = ...; // Fill in your
HealthCentersCapacity array here
float HealthCentersCapacityPerYear[Capacity];
float demandPerYear[DemandPoints][time];


// Distance matrix between facilities and demand points
float demand[DemandPoints][time] =...;// Demand at each demand point

float WeightedDistance[HealthCenters][DemandPoints][time];  // Result
matrix
float U_Max_HealthCentersCapacityPerYear[Capacity];
float U_Min_HealthCentersCapacityPerYear[Capacity];



execute {
    writeln("HealthCentersCapacityPerYear:");
    for (var j in Capacity) {
        HealthCentersCapacityPerYear[j] = 240 * HealthCentersCapacity[j];
        write(HealthCentersCapacityPerYear[j], "\t");
    }
    writeln();
}

execute {
    writeln("demandPerYear:");
    for (var j in DemandPoints) {
      for (var t in time) {
        demandPerYear[j][t] = 3.5 * demand[j][t];
        write(demandPerYear[j][t], "\t");
    }
    writeln();
}}

execute {
```

```
    writeln("WeightedDistance:");
    for (var i in HealthCenters) {
        for (var j in DemandPoints) {
        for (var t in time){
            WeightedDistance[i][j][t] = distance[i][j] * demand[j][t];
            write(WeightedDistance[i][j][t], "\t");
        }
        writeln();
    }
}
}
//upper limit

execute {
    writeln("U_Max_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Max_HealthCentersCapacityPerYear[j] = u_max*
HealthCentersCapacityPerYear[j];
            write(U_Max_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }


//lower limit

execute {
    writeln("U_Min_HealthCentersCapacityPerYear:");

        for (var j in Capacity) {
            U_Min_HealthCentersCapacityPerYear[j] =
u_min*HealthCentersCapacityPerYear[j];
            write(U_Min_HealthCentersCapacityPerYear[j], "\t");
        }
        writeln();
        }


dvar boolean x[HealthCenters][DemandPoints][time];  // Binary decision
variable indicating if facility i serves demand point j
dvar boolean y[HealthCenters][time];  // Binary decision variable
indicating if facility i is located



minimize sum(i in HealthCenters, j in DemandPoints, t in time)
WeightedDistance[i][j][t]* x[i][j][t];  // Objective function to minimize
total distance

subject to {
    // [1] Constraint: Each demand point must be served by exactly one
facility

       forall(j in DemandPoints, t in time) {
    // Constraint to ensure each demand point is served by at least one
health center at each time period
    sum(i in HealthCenters) x[i][j][t] == 1;
}
```

```
     // [2] Constraint: Facility i can only serve demand points if it is
located
    forall(i in HealthCenters, j in DemandPoints, t in time)
        x[i][j][t] <= y[i][t];

    // [3] Constraint: The total number of facilities to be located is
equal to p
    forall(t in time)
    sum(i in HealthCenters) y[i][t] <= (15);


  //[4] The total demand assigned to each facility must not exceed its
capacity
   forall(i in HealthCenters,t in time)
        sum(j in DemandPoints) demandPerYear[j][t] * x[i][j][t] <=
HealthCentersCapacityPerYear[i];



// [6] Current Health Centers will remain open ى
forall(i in HealthCenters,t in time)
if ( i <=9 ) {
  y[i][t] == 1;
}



// [7] if health center is open @ time t it will remain open
forall (i in HealthCenters, t in 1..(T-1)){
  y[i][t+1] >= y[i][t];
}


           // no center to open in the 1st year assuming it takes 2 years
to open a new center
 forall (i in HealthCenters, t in time){
 sum(i in HealthCenters) y[i][1] == 9 ;}

forall (i in HealthCenters, t in 1..(T-1)){
 sum(i in HealthCenters) y[i][t+1] - sum(i in HealthCenters) y[i][t]  <=
(AdditionalCenters) ;
}


    // Constraints specific to your problem (insure Z1 >> Z3 >> Z2), if any
  //[5] The total demand assigned to each facility must not exceed its
capacity
 forall(t in time){
  forall(i in HealthCenters){
   sum(j in DemandPoints) demandPerYear[j][t] * x[i][j][t] <=
U_Max_HealthCentersCapacityPerYear[i]*y[i][t];
  }}


      forall(t in time){
  forall(i in HealthCenters){
```

```
   sum(j in DemandPoints) demandPerYear[j][t] * x[i][j][t] >=
U_Min_HealthCentersCapacityPerYear[i]*y[i][t];
  }}

}

execute {
    writeln("Objective value: ", cplex.getObjValue());

    for (var i in HealthCenters) {
       for (var t in time) {
            if (y[i][t] == 1) {
               writeln("HealthCenter ", i, " is open at time ", t);
                for (var j in DemandPoints) {
                   if (x[i][j][t] == 1)
                        writeln("  HealthCenter ", i, " serves demand point
", j, " at period ", t);
}}}}}
```