ASSIGNMENT PROBLEM FOR HOME HEALTH CARE SERVICES: APPLICATION AT A STATE HOSPITAL IN ISTANBUL

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ASSIGNMENT PROBLEM FOR HOME HEALTH CARE SERVICES: APPLICATION AT A STATE HOSPITAL IN ISTANBUL

Abstract

In recent years, Home Health Care Services has been growing rapidly due to people who have chronic illnesses or physical disabilities, and an increasingly elderly population. Home Health Care Services provides medical care to patients in their own homes. One of the important problems in the Home Health Care Service is the patient assignment problem. The patient assignment problem decides which operators deliver medical care to which patients over the planning horizon.

In this study, an integer linear mathematical model is developed for the patient assignment problem in Home Health Care using real data from one of the largest rehabilitation hospitals in Istanbul, referred to as Hospital X to ensure continuity of care, and balance the operator workloads while keeping patient waiting times low. This model has various specific features of HHCS such as operator's daily capacity, the compatibility between operator and patient, and the continuity of care constraints. Continuity of care is an important concern to obtain sustainability of health. Thus, the developed model has continuity of care as its primary concern. Moreover, due to variability in the number of patients and growth potential of the physiotherapy and rehabilitation services of Hospital X, a rolling horizon algorithm that iteratively solves an integer linear model is used for assigning patients to operators. The developed model was tested under three different simulated scenarios. Operators serve only one district in scenario 1, two districts in scenario 2, and every district in scenario 3. Results demonstrate the performance of the developed model, especially in terms of provided continuity of care and decreased waiting times and the best results were obtained in the scenario 3 since it has the highest service flexibility.

Keywords: Home Health Care, Continuity of Care, Patient Assignment, Mixed Integer Programming

EVDE SAĞLIK HİZMETLERİ ATAMA PROBLEMİ: İSTANBULDA BİR DEVLET HASTANESİ UYGULAMASI

Özet

Son yıllarda, kronik hastalıkları veya fiziksel engelleri olan kişiler ve artan yaşlı nüfusu nedeniyle Evde Sağlık Hizmeti hızla büyümektedir. Evde Sağlık Hizmeti, hastalara kendi evlerinde tıbbi bakım hizmetinin gerçekleştirilmesini sağlar. Evde Sağlık Hizmeti'nin en önemli sorunlarında biri de hasta atama problemidir. Hasta atama problemi, planlama ufku içerisinde hangi operatörlerin hangi hastalara tıbbi bakım hizmeti vereceğine karar verir.

Bu çalışmada, hastaların tedavi almak için bekleme süresini mimimumda tutarken bakımın sürekliliğini sağlamak ve operatör iş yüklerini dengelemek için İstanbul'daki en büyük rehabilitasyon hastanelerinden biri olan X Hastanesinden alınan gerçek bir veri seti kullanılarak Evde Sağlık Hizmetleri Atama Problemi için bir karma tamsayılı doğrusal matematiksel model geliştirilmiştir. Bu model, operatör kapasitesi, operatör ve hasta arasındaki uyumluluk ve bakım sürekliliği kısıtı gibi Evde Sağlık Hizmeti'nin çeşitli spesifik özelliklerine sahiptir. Bakımın sürekliliği, sağlığın sürdürülebilirliğini sağlamak için önemli bir husustur. Bu nedenle, geliştirilen modelin birincil amacı bakımın sürekliliğini sağlamaktır. Ayrıca, X Hastanesi'nin hasta sayısındaki değişkenlik, hasta tedavi taleplerindeki değişkenlik ve fizik tedavi ve rehabilitasyon hizmetlerinin büyüme potansiyelinden dolayı modeli, hastaların tedavi periyodunun ilk gününde operatörler sabitlenerek ve operatörler sabitlenmeden çözüm yapılması için yuvarlanan ufuk algoritması kullanılır. Geliştirilen model, üç farklı simülasyon senaryosu altında test edilmiştir. Operatörler senaryo 1'de yalnızca bir ilçeye, senaryo 2'de iki ilçeye ve senaryo 3'teki her ilçeye hizmet vermektedir. Sonuçlar, geliştirilen modelin performansının özellikle sağlanan bakım sürekliliği ve azalan hasta bekleme süreleri açısından iyi olduğunu göstermektedir ve en iyi sonuçların en yüksek hizmet esnekliğine sahip olan senaryo 3'te olduğu gözlemlenmiştir.

Anahtar kelimeler: Evde Sağlık Hizmeti, Bakımın Sürekliliği, Hasta atama, Karışık Tamsayılı Programlama

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To my family. . .

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List of Abbreviations

GA	**G**enetic **A**lgorithm
GRASP	**G**reedy **R**andomized **A**daptive **S**earch **P**rocedure
HHC	**H**ome **H**ealth **C**are
HHCRSP	**H**ome **H**ealth **C**are **R**outing **and** **S**cheduling **P**roblem
HHCS	**H**ome **H**ealth **C**are **S**ervices
IP	**I**nteger **P**rogramming
ILP	**I**nteger **L**inear **P**rogramming
MIP	**M**ixed **I**nteger **P**rogramming
NOBC	**N**umber of **O**perators who visit **B**y **C**ar
NOBF	**N**umber of **O**perators who visit **B**y **F**oot
TNO	**T**otal **N**umber of **O**perators
TS	**T**abu **S**earch
US	**U**nited **S**tates
VNS	**V**ariable **N**eighborhood **S**earch
a_{jk}	Daily operator capacity
b_{ij}	Receiving care service of patient i by operator j
c_{ig}	Compatibility between patient i and district g
d_{ik}	Demand for care by patient i in day k
f_k	Maximum number of patients served by operators in day k
G	Set of districts
I	Set of patients
J	Set of operators
K	Time horizon
m_{jg}	Compatibility between operator j and district g

$nPatOp_{ij}$	Assignment of patient i to real operator j
$waitedPat_i$	Waiting time of patient i
w_i^1	Weight of waiting patients
w_{ij}^2	Weight of patient operator assignments
x_{ijk}	Assignment of operator j to patient i in day k

Chapter 1

Introduction

Nowadays, due to an increase in operational cost and several limitations related to customers or service operators, the service industry tries to provide better service quality while minimizing costs. Especially, this challenge has crucial importance for mobile services. Mobil services that include visiting customers by service operators and serving at customer's locations. One of the most rapidly growing mobile services is Home Health Care (HHC) that includes providing medical care services to ill and underprivileged or disabled or elder people at their homes. HHC includes a wide range of Home Health Care Services (HHCS) that are provided in patient's homes by skilled medical professionals [1]. According to Lanzarone and Carello, the HHC is defined as delivering medical, paramedical, and social services to patients at their homes instead of in a hospital [2]. HHC activities include diagnostics, medical examination, test, treatment, medical care, and rehabilitation service, and prescribing drugs that will be used for a long period of time [3].

The main attributes of HHC are patients, operators, and service demand as shown in Figure 1.1. In HHC, patients are categorized according to geographical locations. Patients are also categorized into several care profiles based on the specific needs of their treatment in terms of human and material resource requirements. The treatment process of a patient continues until the patients get healthy in HHC and this treatment process should not be skipped even for one day.

In HHC, each patient receives care from a set of operators according to a needed care plan. HHC includes different categories of operators such as nurses, doctors, physicians, and physiotherapists, etc. Each operator has a specific skill and territory where he/she practices. Another important factor of HHC is a service demand where service demand varies from patient to patient because each patient has a different care profile. Also, service demand is highly uncertain due to unexpected changes in patient's conditions such as cancellation of appointments, misremembering the appointment date, change of patient's address, etc.

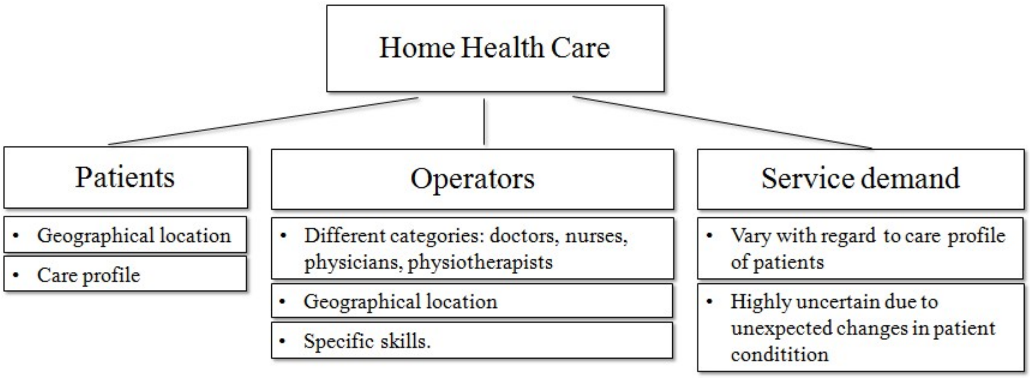

Figure 1.1: Main characteristics of HHC.

Important aspects of HHC are as follows,

Continuity of care: Continuity of care means that a patient is visited by the same operator during his/her treatment process. To avoid information loss through the cycling of operators, the patient requires receiving care from the same person instead of being obliged to continuously developing new relationships with new operators [2].

Patient satisfaction plays important role in the evaluation of HHCS quality. Studies that have been carried out in Norway showed that the continuity of care not only increases patient satisfaction but also saves time by accumulating a medical history of patients for operators [4]. Providing the continuity of care in HHCS refers to ensuring patient satisfaction and safety. Thus, providing continuity of care is a common goal for patients and service providers in HHCS.

Workload balance: It refers to the balanced number of patients visited or total delivered service time by operators. When the number of patients visited or total delivered service time by operators is not to be distributed equally, it causes problems such as dissatisfaction of operators, fatigue, and resignation.

Patient-Operator compatibility: Each operator belongs to a district where he/she operates in the HHC. In the assignment of operators to patients, patients and operators should belong to the same district.

Qualification/skill: In the HHC, operators have different qualifications/skills for patients who have different care profiles. The qualifications/skills of health care workers who are assigned to the patient have to match the requirements of the patients.

Capacity: Each operator has working time capacity and performs patient visits without exceeding working time capacity.

To receive HHCS, patients can request via a call to the HHC department of hospital or mail to the HHC department of a hospital. This request can be done by a patient or patient relative. The contacts, address, and requested service type information of patients are registered to the HHCS program by the HHC planner in the HHC department of the hospital. After this application, the patients are visited by a health team that includes the specialist physician at their home for pre-assessment, and their health state is determined.

According to the pre-assessment of the specialist physician, the care plan of the patient is created and the assigned operator is determined for this patient. Then, care visits of patients begin by the assigned operator. The flow of the HHCS system is as shown in Figure 1.2. As HHCS has many advantages for patients and HHCS providers when compared to hospital care, patients prefer to receive care at home, and HHCS providers prefer to offer medical services at patients' home. In terms of patients, receiving customized medical care concerning health requirements at home instead of hospital care is more comfortable and safer.

Figure 1.2: The flow of the HHCS system.

In a hospital, an operator has to treat a large number of patients but s/he can contact personally with his patient at home and the risk of infection at home is much lower compared to the hospital. The other advantage of HHCS for patients is that it eliminates social isolation.

Thanks to HHCS, the patients are not isolated from their social life and can spend more time with their family and friends at home during their treatment process. In terms of service providers, offering medical care to patients at home instead of hospital care is less costly than providing the same service in a hospital [5]. Because of the higher facility and operating costs in conventional hospitalization, providing medical care to patients at home is more economical for HHCS providers.

In recent years, the demand for HHC is growing rapidly in European countries and other regions. There are three reasons for this rapid growth of HHCS. The first reason is chronic illnesses and physical disabilities.People who have a chronic illness or physical disabilities performed many activities such as receiving treatment, getting an education, socializing, etc. at home during their lifetime and they need HHCS. The second reason is that people recovering from surgery or acute illnesses require HHCS. After surgery or having acute illnesses, patients need to stay at home for recovering more quickly or keeping safe from infection.

The third reason is the increase in the elderly people population and the high operational costs of the hospital [6]. The increase in the elderly people population and high operational costs of the hospital has caused a serious demand increase in HHCS around the world [7]. In terms of Turkey, elderly population data and estimations for the future are shown in Table 1.1 that shows that the elderly population will increase over the years and bring the demand increase for HHC [8].

Years	**Total population (million)**	**Persons aged 65+ (million)**	**Ratio of elderly people in the total population (%)**
2018	82.867.223	7.163.354	8,7
2023	86.907.367	8.867.951	10,2
2040	100.331.233	16.373.971	16,3
2060	107.095.998	24.242.787	22,6
2080	107.100.904	27.413.359	25,6

Table 1.1: Number and share of population age 65+ in Turkey, 2018 to 2080.

Also, according to a study by Grand View Research, the size of the global HHC market was $281.8 billion in 2019 and there is a growing expectation for the size of the global HHC market with a growth rate of 7.9% from the year 2020 to 2027. Due to the high demand increase in HHC, service providers of HHC have faced several operational issues and management problems. These problems faced by HHCS providers have attracted the attention of many researchers. Therefore, the number of research about HHCS has increased especially within the last two decades. In Figure 1.3, the increase in the number of researches about HHCS is illustrated by searching keywords as “home health care service”, “operational research”, and “home health care problem” in Science Direct.

When these studies are examined, it is realized that considering all of the requirements by stakeholders in HHCS may lead to some problems. There are three key stakeholders in HHCS; patients, operators, and health care service providers. Each stakeholder has specific requirements. Planning period, service territory, given service type, continuity of care, etc. constitute the requirements of the health care service providers in HHCS. Frequency of visit, visit date, and personal preferences, etc. constitute the requirements of the patients.

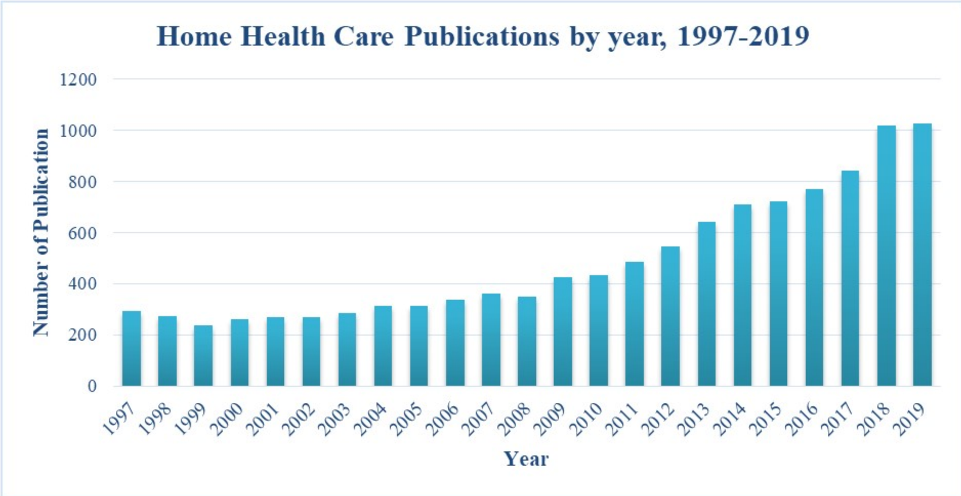

Figure 1.3: Published articles about HHC in Science Direct.

In terms of operators, these requirements are working hours, workloads, skills, territory preferences, etc. Considering these requirements concurrently increases the complexity of the problem. When the literature is examined, it is seen that the classical assignment and routing problem encloses the characteristic of HHCS and presents the most appropriate solutions to satisfy all requirements of stakeholders.

In this study, we focus on the patient assignment problem to decide which operators in a certain territory will deliver the needed care service to which patients. Furthermore, we analyze a real case using data from the HHC department of a large physiotherapy and rehabilitation Hospital in İstanbul, referred to as Hospital X from now on. Hospital X provides neurological rehabilitation services at home to patients who have cerebral palsy, spinal cord injury, hemiplegia, paraplegia, parkinson, etc. HHC department of Hospital X has 25 operators and serves patients in 12 districts of the Anatolian side of Istanbul. HHC department of Hospital X faces many problems such as low patient satisfaction due to long waiting times to receive medical service, non-continuous care provided by different operators in each visit, and also low operator satisfaction due to lack of workload balance among operators, job rotation requirements, etc. This thesis aims to achieve better management of these issues.

We developed an integer linear mathematical model for the patient assignment problem in Home Health Care using real data from Hospital X to ensure continuity of care, and balance the operator workloads while keeping patient waiting times low. Then, the effects of different parameter settings on the solution are analyzed under different scenarios. The number of patients in the system is increased during the planning period by taking into consideration the growth potential of the HHCS system.

The rest of the thesis report is organized as follows. In Chapter 2, a literature review related to the HHC scheduling problem is provided. The mathematical model to optimize the scheduling in HHCS is presented in Chapter 3 and the rolling horizon approach is explained. Chapter 4 shows computational results and evaluations of the case study and designed scenarios. Finally, Chapter 5 concludes the study and discusses some possible future research directions.

Chapter 2

Literature Survey

The increase in the elderly people population and high operational costs of the hospital has caused a serious demand increase in HHC. With the increasing demand for HHC, HHCS providers have encountered several operational issues and management problems. Thus, HHCS providers need to optimize their HHC operations. In this chapter, we review the existing literature on HHC and introduce the patient assignment problem and its characteristics and constraints.

The assignment problem on HHC refers to the allocation of a set of operators to patients in a certain region [9]. This type of problem consists of three key stakeholders; patients, health care workers, and health care service providers. Each stakeholder's specific needs add up to the complexity of the problem.

Cissé *et al.* [10] divided specific constraints of each stakeholder into three classes as temporal constraints, assignment constraints, and geographic constraints, respectively. The first class includes constraints that have a time relationship or a frequency–over–time relationship. For instance, determining the starting time of a patient in HHCS or service time of an operator according to his/her schedule, etc. Assignment constraints have a high impact on the relationship between health care workers and patients unlike time relation in temporal constraints. Mostly, these constraints in the second class determine which operator of a certain category will deliver the care service to which patients.

Actors	Temporal Constraints	Assignment Constraints	Geographical Constraints
HHC service organization	- Planning horizon - Frequency of decision	- Continuity of care	- Sectors/districts - Typology of HHCS provided
Patient	- Frequency of visits - Time windows - Temporal dependency - Disjunctive services	- Preferences	- Type of network between home locations
Care worker	- Contract type - Capacity/working hours	- Qualification/skill - Workload balancing	- Location of care workers

Table 2.1: Classification scheme based on constraints [10].

The last class is geographic constraints that deal with territorial considerations such as the patient's location, the territory served by health care workers, etc. The classification depending on the constraints designated in the study of Cissé *et al.* [10] is shown in Table 2.1.The remainder of this section reviews modeling types of existing researches on the HHC assignment problem according to constraints in Table 2.1, namely temporal, assignment, and geographic constraints in HHCS organizations. Initially, we begin with temporal constraints for an HHCS organization. In HHC, *the planning horizon* refers to the period of HHC scheduling that is executed by the HHCS provider. The length of the planning horizon can be one day, one week, one month, etc. and it can be changed according to availability of the length of the planning horizon before scheduling. When the length of the planning horizon increases, the accuracy of scheduling will decrease because of the lack of information [10]. For the models of assignment problems on HHC, the planning horizon is generally selected as one day or one week. Mankowska *et al.* [11] proposed a model for the daily planning of HHCS to optimize economical and service-oriented performance measures such as the total distance traveled by all caregivers, the total tardiness of services, and the maximum tardiness among all service operations respectively. In addition to the proposed mathematical model, they presented various heuristic solution methods such as Variable Neighborhood Search and Adaptive Variable Search. Liu *et al.* [12] presented two MIP models to minimize the total vehicle cost of daily logistic activities such as delivering drugs and medical devices from its pharmacy to patient's home using Tabu Search (TS) and Genetic Algorithm (GA) for a real case study in HHC Company in France.

Bard *et al.* [13] constructed a model that aims to minimize the travel, treatment, and administrative costs for the weekly tours of therapists considering contractual agreements, labor laws, and time preferences of patients by using a greedy randomized adaptive search procedure (GRASP). Wirnitzer *et al.* [14] developed five MIP models for a monthly home care nurse rostering planning to maximize continuity of care, as it is discussed in the Introduction, which is vital for home health care providers to measure the satisfaction level of patients while considering nurse availabilities, daily and monthly working time restrictions, and patient-nurse compatibilities. Hewitt *et al.* [15] carried out a study different from the others [11]-[13]. Instead of analyzing a week or a shorter planning horizon, examined the long planning horizon length as two to three months considering the continuity of care and demonstrated that a long planning horizon is superior to a short planning horizon in terms of transportation cost and staffing levels savings.

Next, we explain how assignment constraints for an HHCS organization are handled in the literature. The *continuity of care* is very important in the assignment constraints of HHCS providers. It means visiting patients by the same health care worker during the patient's treatment process as mentioned in the Introduction. Providing continuity of care is one of the main goals of HHCS providers. HHCS providers aim to increase service quality and strengthen the relationship between health care workers and patients by providing continuity of care because the continuity of care prevents the loss of information among health care workers. HHCS can be provided to patients in three forms; full, partial and no continuity of care by HHCS providers [10]. During the treatment process, one and only one health care worker is assigned to patients in the full continuity of care. According to partial continuity of care, more than one health care worker delivers medical care to patients but this number should remain at the minimum level possible.

Lastly, the visit of the patient can be carried out by any available health care worker regardless of being the same medical staff in the previous visit of the patient is the no continuity of care situation which is desired neither by patients nor by the HHCS provider. Gamst and Jensen [16] used the branch-and-price algorithm in the HHC scheduling problem. In this study, first, a one-day plan is generated for each employee then all generated daily plans are merged into a master schedule considering regularity constraints. They mentioned continuity of care as employee regularity in their study. They aimed that all visits of a patient are conducted by the same medical staff and minimized the sum of the visits of a citizen by the number of different employees on the objective function for providing employee regularity. Another study that considers continuity of care was conducted by Nickel *et al.* [17] in 2012. In this study, continuity of care is indicated as the patient-nurse loyalty that means visits of patients during the planning horizon are delivered by the same nurse. They defined the patient-nurse loyalty as a binary variable and they minimized the sum of the patient-nurse loyalty variable multiplied by a penalty coefficient to each patient in the objective function to provide continuity of care. As the study of Nickel *et al.* [17], Wirnitzer *et al.* [14] considered continuity of care for the monthly nurse rostering of a German home care provider. They minimized the assignment of the number of different nurses between two subsequent visits of each patient. Continuity of care is handled mostly directly in objective function in models, however, Cappanera and Scutella [18] incorporated the continuity of care in their model as a constraint instead of adding to the objective function. With this constraint, they limit the number of operators that can be assigned to each patient for the weekly planning horizon. Thus, they reduce the loss of information among operators and increase service quality. Finally, the continuity of care is also important for maternity services that include pregnancy, childbirth, and after birth care services in addition to HHCS because each pregnant woman requires receiving care services by the same midwife.

Bowers *et al.* [19] studied the assignment and routing of midwives using multiple traveling salesmen problem algorithms. They aimed at performing antenatal and postnatal care for each mother by the same midwife to help to build a better relationship between mothers and midwives.

Geographic constraints are the other important constraint class for HHC providers. HHCS providers can classify health care workers according to districts or skills of health care workers. Easier management of health care teams and reducing travel times of health care workers are provided with this classification. The classification considers single or multiple districts. Mankowska *et al.* [11] provided a mathematical model for the Home Health Care Routing and Scheduling Problem (HHCRSP). They considered routing staff members and scheduling a single service that includes one service operation to be delivered by a single staff member and double service operations that include two service operations to be delivered by two staff members. They used a single service district and did not need to categorize workers according to multiple districts. Lanzarone *et al.* [20] examined single districts and multiple district cases in their study. They developed mixed-integer mathematical models to balance the workload of the operators considering several properties of HHCS such as the continuity of care, operator's skill, and geographical areas.

Besides the classical medical care services, HHCS providers offer services such as the delivery of drugs or materials, collection of blood or biological sample, and urine sample, etc. The complexity of the assignment and routing problems on the HHCS is due to the characteristics and requirements of each particular service. Liu *et al.* [12] studied daily logistic activities such as delivering drugs and medical devices from its pharmacy to patient's home using TS and GA and Kergosien *et al.* [21] proposed a mathematical model and two different metaheuristics; TS and VNS for the planning of blood sample collection service appointments of patients and visit routes by health care personnel.

In addition to constraints about the HHCS organization, there are also constraint types related to patients in the literature. In HHC, *the frequency of visits* refers to the number of visits of patients at home by the operator during the care plan. The frequency of visits can vary from patient to patient as each patient has a different care profile or service type requirement. In the literature, the patient's visit frequency is observed as once-per-day, once-per-week, and several-times-a-week.

Hiermann *et al.* [22] developed a new two-step solution for multi-modal HHC scheduling problems for the Austrian HHCS provider by using one of four meta-heuristics: VNS, a memetic algorithm, scatter search, and a simulated annealing hyper-heuristic. They aimed to assign home-care staff to patients and to find efficient multi-modal tours considering staff and customer satisfaction. In the problem definition of this study, it is stated that patients should be visited every day by staff. In the study of Rasmussen *et al.* [23], the patient's frequency of visit is used several times a day. They developed a model for the home care crew scheduling problem using a branch-and-price solution algorithm. Lastly, Nickel *et al.* [17] and Kergosien *et al.* [21] used the patient's frequency of visits several times a week in their study. Bard *et al.* [13] used the patient's frequency of visit as once a week in their study.

The *time window* refers to the time period patients are available at home to receive HHCS in the literature. There are two cases for the time window in the models of assignment and routing problem on HHC. The first one is that the time interval of care visits may not be accepted by patients or a patient requires receiving care at a certain time. The visit of a patient has to be delivered within the specified time window in the first case [9, 13]. In the second case, time windows are handled as soft constraints by the decision-maker [11, 22]. The violation of the time window that is specified by patients is limited in this way and the model is forced to minimize penalty costs. Duque *et al.* [24] studied the scheduling of the visits of patients in a certain time interval for a Belgian HHCS provider.

They aimed to maximize the service level and to minimize the traveled distance while considering the continuity of care for the patient visits that can be up to five times per week. The case in this study allows patients to choose time windows preferences. In the assignment problem on HHC, besides the time window constraint, there is another constraint type. *Preferences* of patients affect the decision on which operators of a certain category will deliver the care service to which patients. For instance, a patient may reject to receive care from an operator due to gender incompatibility, smoking behavior of nurses, or personal reasons. This situation is observed in the study of Wirnitzer *et al.* [14] and the compatibility between patients and nurses is controlled with a binary parameter in their model. Bertels and Fahle [25] have provided preference which is receiving care from certain nurses of patients in their model on the HHC problem by a penalty cost.

Some other important constraints in the patient assignment problem are as follows: capacity/working hours, qualification/skill, workload balancing, etc. Health care workers are employed full time or part time and their working hours capacity such as eight hours a day. The exceeding of health care worker's working time capacity is prevented by working time restriction constraints on the mathematical model. Trautsamwieser and Hirsch [7] optimized the daily scheduling of the nurses using VNS considering working time regulations, hard time windows, and mandatory breaks of nurses. They proposed a mathematical model and metaheuristic approach that minimizes the dissatisfaction level of clients and nurses and the traveling time of the nurses. The maximum allowed working time of nurse and break mandatory is controlled with an upper limit. Nickel *et al.* [17] considered the weekly planning problem of HHCS by using real-world data from Germany and the Netherlands. In this study, violation of a nurse's working time that is covered by the contract is allowed with a high penalty in the objective function.

Bowers *et al.* [19] studied the planning of antenatal and postnatal care for each mother by the same midwife who works part-time to help to build a better relationship between mothers and midwives. The complexity of this planning is that considering the assignment of part-time working midwives to mothers and the continuity of care because part-time working hours complicate handling continuity of care. Wirnitzer *et al.* [14] considered the planning of monthly nurse rostering for two full-time employed nurses and thirty-eight part-time employed nurses. They prohibited exceeding the daily working time of a nurse by using the legal upper limit on the working time restriction.

While assigning health care workers to patients, the decision-maker should consider the compatibility between patient and health care worker. Health care workers have to satisfy the qualification/skill requirements of the patient assigned to him/her. Lanzarone *et al.* [20] studied models to assign operators who have main and/or additional skills to patients in their study. In this study, all requirements of a patient are met by an operator in the related category. The last important constraint that affects assignment problem on the HHC for health care workers is *workload balancing*. The number of patients assigned to operators or total delivered service time is not guaranteed to be distributed equally due to the lack of medical staff or material resources by the HHCS provider. The workload imbalance among operators causes problems such as dissatisfaction with operators, fatigue, and resignation. However, assuring the continuity of care makes it harder to balance the workloads in the models of the assignment problem on HHCS. Bachouch *et al.* [26] proposed a model for the assignment of nurses in a French HHC office. They provided workload balance among health care workers in their study by minimizing the difference between the upper bound of the workload of each nurse and the lower bound of the workload of each nurse on the objective function of the model for the increasing delivered care quality.

Blais *et al.* [27] have studied workload balancing among nurses for the Côtedes-Neiges CLSC in Montreal by using the TS heuristic algorithm. The difference of this problem from the literature is that they measured workload not only by the time spent with patients but also included the time spent traveling between visit locations.

In conclusion, while the current literature on HHCS includes many studies with different constraint types, the patient assignment problem is not considered under workload balancing constraints together with the continuity of care requirements except in a few articles [20], [22]. This study aims to fill this gap in the literature. Also, the assignment problem on HHC includes uncertain parameters. One of the most uncertain parameters is the service demand of patients. Service demand parameter is highly uncertain due to unexpected situations in patient's conditions such as registration date, cancellation of appointment, misremembering the appointment date, change of patient's address, etc. Because of the uncertainty of the service demand parameter, the planning process needs daily updating. Thus, the rolling horizon approach is applied to provide daily updating in this study. With the rolling horizon approach, new changes in parameters are integrated into the system without changing the assignments made in the previous day. Another characteristic of this thesis is a representation of a real-life case study about physiotherapy and rehabilitation services by Hospital X. In this thesis, firstly operators are assigned to patients. Then, the job rotation among the operators is performed. Districts cannot be visited by the same operator for more than three months. Operators assigned to districts are rotated every three months by the hospital. With this rotation, the communication of operators with patients independently from the hospital are prevented. Moreover, due to the growth potential of the HHCS system, the effects of different parameter settings on the solution are examined under-designed scenarios with generated random data.

To conclude this section, Table 2.2 highlights important aspects of existing articles on assignment and routing problems on HHC. In Chapter 3, the proposed model for assignment problem on HHCS and rolling horizon approach that provides to update variations in parameters are presented.

Article	Assignment problem	Routing problem	Purpose	Solution Method
Bachouch *et al.* [26]	✓	✓	Minimize the total traveled distance	Integer Linear Programming (ILP)
Bowers *et al.* [19]	✓	✓	Minimize the total traveling time	Multiple Travelling Salesmen Problem Algorithm
Cappanera and Scutellà [18]	✓	✓	Balancing of two obj. Function (minmax & maxmin)	ILP
Cappanera *et al.* [28]	✓	✓	Balancing of the caregiver workload under continuity of care & skill constraints	Branch and Bound
Carello and Lanzarone [2]	✓		Minimize overtime costs and cost associated to reassignments	Linear programming
Carello *et al.* [29]	✓		Investigating the patient assignment problem in HHC under continuity of care for perspectives of HHC's stakeholders	Threshold method
Cissé *et al.* [10]	✓	✓	Overview of existing OR models	Branch-and-price Solution Algorithm, ILP, MIP and Local Search, Constraint Programming, TS and Adaptive Large Neighborhood Search, etc.
Decerle *et al.* [30]	✓	✓	Minimizes total travelling time of the staff members	Memetic algorithm
Erdem and Bulkan [31]	✓	✓	Developing two-stage solution approach for HHC routing & scheduling problem	MIP, Neighborhood Search
Fikar and Hirsch [32]	✓	✓	Overview of existing HHC routing and scheduling works	VNS, GA, TS, Branch and Price, Fuzzy Simulated Evolution, Simulated Annealing, etc.
Grieco *et al.* [33]	✓	✓	Review of existing model in HHC	Heuristic approaches, MIP, IP,GA,VNS,TS and Adaptive Large Neighborhood Search, etc.
Guericke and Suhl [34]	✓	✓	Minimizes driving and waiting times and unassigned visits	MIP, Adaptive Large Neighborhood Search
Hewitt *et al.* [15]	✓	✓	Minimize transportation cost staffing requirement	Heuristics
Lanzarone *et al.* [20]	✓	✓	Balance the workloads of the operators	MIP
Lin *et al.* [35]	✓	✓	Minimizes total costs of nurse's overtime and vehicle routing	Harmony Search
Milburn *et al.* [36]	✓	✓	Minimize travel cost, Maximize patient satisfaction and nurse satisfaction	Multi-Objective Programming Metaheuristic Using an Adaptive Memory
Nasir and Dang [37]	✓	✓	Minimizes route cost, nurse dissatisfaction cost and patient dissatisfaction cost	Neighborhood Search
Nickel *et al.* [17]	✓	✓	Minimize total traveling distance and overtime costs unscheduled	Constraint programming & Metaheuristics
Quintana *et al.* [38]	✓	✓	Minimizes total travel time, total idle time and number of caregivers	Greedy Approach
Trautsamwieser and Hirsch [7]	✓	✓	Minimize the traveling time of the nurses, the dissatisfaction level of clients and nurses	VNS Algorithm
Wirnitzer *et al.* [15]	✓	✓	Maximize continuity of care	MIP
Yalcindag *et al.* [39]	✓	✓	Balance the trade-off between care giver workload and their total travel times	Kernel Regression Technique

Table 2.2: Summary of publications about Assignment and Routing Problem on HHC.

Chapter 3

Deterministic Mathematical Model

3.1 Introduction

In this thesis, we developed an integer linear model for the patient assignment problem on HHC. The current HHC scheduling process of physiotherapy and rehabilitation Hospital X, the proposed mathematical model, and the rolling horizon method are presented in this chapter.

Hospital X is a physiotherapy and rehabilitation hospital in Istanbul. HHC department of this hospital offers neurological rehabilitation services only to certain types of patients, such as cerebral palsy, spinal cord injury, hemiplegia, paraplegia, parkinson, etc. 25 operators are working in this department of Hospital X; 12 of them visit patients at home by car and 13 of them visit the patient as a pedestrian. They make visits from Monday to Saturday between 9:00 am and 4:00 pm. Since Hospital X has just started to serve in HHCS, the HHC department of hospital currently provides in 12 districts; Ataşehir, Beykoz, Çekmeköy, Kadıköy, Kartal, Maltepe, Ümraniye, Üsküdar, Pendik, Sancaktepe, Sultanbeyli, and Tuzla as shown in Figure 3.1 and Table 3.1. In Table 3.1, the first column shows served districts. The second column and the third column shows the number of operators who visit by foot *(NOBF)* and the number of operators who visit by car *(NOBC)*, respectively. The last column shows total number of operators *(TNO)* in Hospital X.

Figure 3.1: Districts served by operators of the HHC department of Hospital X.

Hospital X waits for the number of patient requests in that district to reach a sufficient number to start serving in a district. If a sufficient number of the patient cannot be reached, it does not start to provide service in that district.When a patient desires to receive service from the HHC department of the hospital, s/he can call the hospital or send an e-mail to request. This request also is done by the patient's relative or friend. Patient's contacts, address, and requested service type information is registered to the HHCS program by the HHC planner in the the hospital. Then, the HHC planner adds this new request to the list of patients to visit. Until the number of patient request in the district where there are patients on the waiting list reach a sufficient level, patients wait for a long time to receive service. After a long waiting time, the patients are visited by the health team that includes a physician trained in HHC, HHC technician, and assistant health personnel at their home for pre-assessment and their health state is determined. For this patient, a care plan is created and the assigned operator is determined according to the pre-assessment of the specialist physician. Then, the patient's regular care visits start by an assigned operator. The flow of the HHC department's scheduling process is as shown in Figure 3.2. The schedule of HHCS is currently done manually in this hospital and the planning process is very complex and time-consuming due to requirements of patients and operators such as continuity of care, working hours, etc.

District	NOBF	NOBC	TNO
Ataşehir	1	1	2
Beykoz	-	1	1
Çekmeköy	-	1	1
Kadıköy	6	1	7
Kartal	1	1	2
Maltepe	2	1	3
Pendik	-	1	1
Sancaktepe	-	1	1
Sultanbeyli	-	1	1
Tuzla	1	-	1
Ümraniye	1	2	3
Üsküdar	1	1	2
Toplam	**13**	**12**	**25**

Table 3.1: The number of operators working in each district.

Another difficulty of the planning process is uncertainty in patient preferences. For example; a patient may decide to cancel the appointment or s/he may sometimes need to reschedule the appointment for a later date, etc. These unexpected situations cause uncertainty in patient preferences. Thus, the planning process needs daily updating because of uncertainties in patient preferences. The important issues are that this hospital faces low patient satisfaction due to the waiting time of patients to receive service, non-continuous care, and workload imbalance among operators. Moreover, there is a job rotation among operators in Hospital *X*. Operators cannot serve the same district for more than three months. The reason for this rotation is to prevent the communication of physiotherapists working in Hospital *X* with patients regardless of the hospital. Also, the reason for the rotation every three months is to provide continuity of care and for an operator who has adopted the district to complete his/her patient's treatment. Thus, we propose a mathematical model to overcome problem encountered by this hospital and aim to achieve obtaining daily optimal schedules that reduce the waiting time of patients to receive care, provide workload balance for operators, and continuity of care for patients. The developed integer linear model includes multi objectives.

Figure 3.2: The flow of the scheduling process of the HHC department.

These objectives aim in balancing the workloads of the operators, providing continuity of care for the patients, maximizing operator utilization and minimizing waiting time of patients to receive care. Although considering workload balance and continuity of care together complicates the assignment problem and lead to increase waiting time to receive care of patients, added some parameters and constraints into the model prevent long waiting time of patients to receive care. The case study of Hospital X is analyzed by the developed model. As HHCS for Hospital X is a newly developing system and there are not enough patient applications in each district, experiments based on randomly generated instances are conducted under different scenarios to test the performance of the model and analyzed their results. Currently, the number of patients in some districts where are served by Hospital X is very small. When the number of patients in the system increases, the results of these experiments are considered to be a guide for decision-makers of the HHC department in the hospital about making strategic decisions. Moreover, the effect of job rotation among operators on the utilization of operators and continuity of care is investigated by the developed model.

These investigations are introduced in detail in the following subsections. The proposed deterministic mathematical model is explained in Section 3.2 and applied rolling horizon approach is defined in 3.3.

3.2 Proposed Model

The daily HHC schedule is optimized through an integer linear model that aims to provide continuity of care, balance workload among operators, increase operator utilization, and reduce waiting times of patients over the planning horizon.

I represents a set of patients in the scheduling system of HHCS. There is a set of operators in the model; J shows a set of operators and this set also includes j^d dummy operator to track patients waiting for receiving care. Untreated patients are assigned to the dummy operator, i.e. their treatments are being delayed. For example, when patient i who requires service cannot be assigned to any operator, they are assigned to dummy operators in the system and they wait to receive treatment until an operator is available. A set of days K is considered as planning horizon and all days $k \in K$ over the planning horizon of scheduling. Moreover, the set of the district where patients live and operators deliver HHCS is denoted with G.

In the proposed model, the care visit requirement for HHCS of each patient registered in the HHC system is represented by d_{ik}. This demand parameter d_{ik} indicates whether patient i on day k requires care visit or not. Also, the daily treatment capacity of each operator on day k of the planning horizon is represented by a_{jk} parameter and expressed in the number of patients. Each day, operators serve at most eight patients. In HHC, HHCS providers classify operators according to districts and each operator provides service to one or more district. Thus, compatibility between the district of patient and district of the operator is controlled by m_{jg} and c_{ig} parameters. These parameters m_{jg} and c_{ig} are Boolean parameters, m_{jg} =1 if operator j serve to district g and 0 otherwise and c_{ig} =1 if patient lives in district g and 0 otherwise.

In the proposed model, the assignment of operator j to patient i on the day k is denoted by x_{ijk}. On each day, operators should visit at most the average number of patients in the system.
The average number of patients in the system changes every day, as new patient registrations or patients are leaving the system because of the completion of treatment every day. We desire the number of patients in the system to be allocated equally to the operators for providing a balanced workload among operators. To investigate the continuity of care, it is checked that whether or not the operator j visits the patient i using the b_{ij} binary variable.

Sets	
I	set of patients
J	set of operators
K	time horizon
G	set of districts
Parameters	
a_{jk}	overall operator capacity
m_{jg}	compatibility between operator j and district g
d_{ik}	demand for care by patient i in day k
c_{ig}	compatibility between patient i and district g
w_i^1	weight of waiting patients
w_{ij}^2	weight of patient operator assignments
Decision variables	
x_{ijk}	assignment of operator j to patient i in day k
b_{ij}	receiving care service of patient i by operator j
f_k	maximum number of patients served by operators in day k

Table 3.2: Sets, parameters, and decision variables for the proposed model.

If the operator j visits the patient i, b_{ij} =1 and 0 otherwise. Finally, f_k are positive decision variables stating the maximum number of patients served by all real operators working on day k.The sets, parameters, and decision variables that are used in the model are summarized in Table 3.2.

Variables are subject to the following constraints:

$$\sum_{j=1} x_{ijk} = d_{ik} \qquad \forall i \in I, k \in K \tag{3.1}$$

$$\sum_{j=1|j\neq j^d} x_{ijk} \leq d_{ik} \qquad \forall i \in I, k \in K \tag{3.2}$$

$$\sum_{i=1} x_{ijk} \leq a_{jk} \quad \forall j \in J/\left\{j^d\right\}, k \in K \tag{3.3}$$

$$x_{ijk} \leq \sum_{g=1} m_{jg}\ .\ \ c_{ig} \quad \forall i \in I, j \in J, k \in K \tag{3.4}$$

$$\sum_{i=1} x_{ijk} \geq f_k \quad \forall j \in J/\left\{j^d\right\}, k \in K \tag{3.5}$$

$$\sum_{k=1} x_{ijk} \leq card(k).\ b_{ij} \quad \forall i \in I, j \in J/\left\{j^d\right\} \tag{3.6}$$

$$f_k \geq 0 \qquad \forall k \in K \tag{3.7}$$

$$x_{ijk} \in \{0,1\} \quad \forall i \in I, j \in J, k \in K \tag{3.8}$$

$$b_{ij} \in \{0,1\} \qquad \forall i \in I, j \in J \tag{3.9}$$

Constraints (3.1) imply that each patient has to be assigned to an operator including the dummy operator on the day k of the planning horizon. However, since the first constraint makes an assignment for all operators including dummy ones. Constraints (3.2) are needed to make sure that if there is no demand for a patient, s/he should not be assigned to a real operator. Constraints (3.3) ensure that the total number of patients assigned to operator j in the day k of the planning horizon cannot exceed operator capacity in the day k. Constraints (3.4) prohibit that assignment of operator j to patient i in day k if patient i and operator j do not belong to the same district g. Constraints (3.5) provide that a real operator j serves at least f_k patients in the day k. Continuity of care is considered in Constraints (3.6) by checking whether or not operator j visits the patient i using the b_{ij} during the optimization horizon. Constraints (3.7) define the non-negativity of the variables. Constraints (3.8) and (3.9) show integrality restrictions on the variables.

We have several concerns regarding the solution of the model. The main goals are achieving continuity of care and a balanced operator workload as much as possible. Furthermore, we would like the patients to wait as little as possible for receiving service. Because of these several aims, we have a multi-objective model. To find an optimal or near-optimal solution, we define a weighted objective function where deviations from the goals are penalized. The first objective of the model is to balance the workload of operators over the planning horizon. The second objective of the model is to provide the continuity of care for each patient in the system. Moreover, serving all patients who require care service by operators is the third goal of the model. The fourth objective of the model is to minimize the patient waiting times to receive first care and the last objective of the model is to ensure assignments as few different operators as possible to each patient. All objectives are summed up with various penalizing weights and this sum is minimized as indicated in (3.10).

The objective function Z_1 in (3.11) maximizes the total number of patient visits by operators on a day k. By maximizing (the negative sign for Z_1 in the objective function) the daily minimum of the number of assigned patients to each operator on day k, the operator workload is being balanced. The objective function Z_2 in (3.12) minimizes the receiving care service of patients by more than one operator. The objective function Z_3 in (3.13) minimizes the assignment of patients to dummy operator j^d over the planning horizon and minimizing Z_3 will increase the number of patients receiving care. The objective function Z_4 in (3.14) minimizes the number of patients assigned to real operators weighted by their waiting time before current optimization. In (3.14), x_{ijk} is multiplied with the weight of waiting patient w_i^1 for each patient i. Thus, the model gives priority in the starting of the treatment of the patient who has a large waiting weight w_i^1. The objective function Z_5 in (3.15) minimizes the number of patients assigned to real operators weighted by the number of assignments to each operator before the current optimization. In (3.15), x_{ijk} is multiplied with the weight of patient operator assignments w_{ij}^2 for each pair of patient i and operator j over the planning horizon. Thus, the model gives priority in the assignment of patient i to operator j if s/he has previously received service by operator j.

$$\min\{-10Z_1 + 10Z_2 + 1000Z_3 + Z_4 + Z_5\} \tag{3.10}$$

$$Z_1 = \sum_{k\in K} f_k \tag{3.11}$$

$$Z_2 = \sum_{i\in I} \sum_{j|j\neq j^d\in J} b_{ij} \tag{3.12}$$

$$Z_3 = \sum_{i\in I} \sum_{j^d\in J} \sum_{k\in K} x_{ijk} \tag{3.13}$$

$$Z_4 = \sum_{i\in I} \sum_{j|j\neq j^d\in J} \sum_{k\in K} w_i^1 x_{ijk} \tag{3.14}$$

$$Z_5 = \sum_{i\in I} \sum_{j|j\neq j^d\in J} \sum_{k\in K} w_{ij}^2 x_{ijk} \tag{3.15}$$

3.3 Rolling Horizon Approach

Every day, new patient registrations are made to the HHCS system, or patients whose treatment is completed are left the HHCS system. Thus, parameters in the model are required to be updated daily. Therefore, solving the linear integer model once and keeping the treatment plan same for rest of the planning may not be feasible. This updating is provided by a rolling horizon approach in the experiments based on randomly generated instances. Thanks to rolling horizon approach, we offer the static model to be solved every day for the next seven days. For each rolling day, operators are assigned to patients without changing assignments in the previous rolling day. Therefore, the assignment of an operator to a patient in the previous rolling day is fixed in the rolling horizon approach. These fixed assignments provide continuity of care for patient satisfaction. For this algorithm, we created some specific parameters such as w_i^1, w_{ij}^2, $waitedPat_i$, and $nPatOp_{ij}$. The parameter w_i^1 is used for the weight of waiting patients and w_{ij}^2 is used for the weight of patient operator assignments. The parameter $waitedPat_i$ shows the waiting time of patient i and $nPatOp_{ij}$ indicates the assignment of patient i to real operator j. For new patients in the system, w_i^1 and w_{ij}^2 are assigned to high values like 10. Initially, the value of parameter $waitedPat_i$ and $nPatOp_{ij}$ is 0 as a new patient has not been delayed, and has not been assigned to any operator on the first day of the rolling horizon. We run the model until the last rolling day of the scheduling horizon.

At the end of each rolling day, input data and designed parameters in the model such as the number of patients waiting to receive care, the number of remaining treatments days of a patient who started to receive treatment by an operator, and the number of visit times for patients by the operator assigned them are updated and then, the rolling day k is moved to $k+1$. For example, If patient i requires care visit on day k and there is no available operator for this patient, patient i is assigned to the dummy operator and the waiting time of patient i, $waitedPat_i$, is increased. Also, additional treatment sessions are added to the end of the treatment plans of untreated patients on day k.

For other case, if patient i assigned to a real operator j on day k, then the number of times patient i is assigned to operator j ,$nPatOp_{ij}$, is increased by 1. Furthermore, $waitedPat_i$ and $nPatOp_{ij}$ are used to update w_i^1 and w_{ij}^2 at the end of each rolling day. The weights w_i^1 are redetermined depending on how long patients have waited, and weights w_{ij}^2 used in the model are redetermined based on how many times patients have been assigned to the operators at the end of each rolling day of the rolling horizon algorithm. As we have a minimization problem, smaller weights in the next rolling day optimization push the assignments towards prioritizing longer waiting patients, and keeping the same patient-operator assignments as in the previous rolling day optimization. In this work, the rolling period is considered as 7 days and the assignment model is run at each rolling day over the scheduling horizon, 100 days. The stages of the rolling horizon algorithm are shown in Figure 3.3. The operator-patient assignments are determined at each rolling day using their historical data that is taken from the previous rolling day ensuring the continuity care and workload balance over 100 scheduling days. This approach is implemented in the generated scenarios. These scenarios are called scenario 1, 2, and 3. In scenario 1, all operators are considered as serving only one district. In scenario 2, all operators are considered as serving two districts where are close to each other and all operators are assumed as serving each district in scenario 3. For all scenarios, the workload density of operators is increased using a different daily patient/operator ratio. All ratios of scenarios are run 100 times with fixing the operators on the first day of the treatment period of the patients and without fixing the operators to measure the impact of assignments under continuity of care or continuity of care relaxation on workload balance and waiting times of patients.

Algorithm: Pseudocode of the rolling horizon algorithm

$w_i^1 \leftarrow 10$
$w_{ij}^2 \leftarrow 10$
$waitedPat_i \leftarrow 0$
$nPatOp_{ij} \leftarrow 0$
for k'= 1, … **do**
Get the updated patient, treatment and operator information
Optional: Assign previously treated patients to their existing operators for day k'
$x_{ijk}^* \leftarrow$ Solve the integer linear model for 7 days starting with k'
Implement the resulting optimal policy for k'
$waitedPat_i \leftarrow waitedPat_i + 1$ if patient i is assigned to the dummy operator
Add a session to the end of the treatment plans of the untreated patients on day k'
$nPatOp_{ij} \leftarrow nPatOp_{ij} + 1$ if patient i is assigned to a real operator j on day k'
$w_i^1 \leftarrow 1/\ waitedPat_i$ for $waitedPat_i \neq 0$
$w_{ij}^2 \leftarrow 1/nPatOp_{ij}$ for $nPatOp_{ij} \neq 0$

Figure 3.3: The pseudocode of the rolling horizon algorithm.

For the fixed model, the model is solved again taking into account the operator information assigned in the previous rolling day during the rolling horizon, but fixing the operator assigned to the patient in the previous rolling day is ignored in the not-fixed model.

In the following chapter, the case study: HHCS scheduling of hospital and designed experiments are defined in detail and their results are presented. Then, sensitivity analysis for multi objectives in the model is discussed.

Chapter 4

Computational Results

In this chapter, the computational results of the case study and experiments based on randomly generated instances are presented. The developed mathematical model is implemented in GAMS 23.2 with a CPLEX solver. All experiments are performed on Windows 10 (x64) with `Intel`®Core™ i7(7500 CPU) processor 2.70 GHz and 8 GB RAM.

4.1 Case Study: HHCS Scheduling of Hospital *X*

In this section, we first present the results of the assignment for HHCS using a real data set from physiotherapy and rehabilitation hospital, Hospital *X*. Then, we demonstrate the results of the job rotation that is requested from Hospital *X*. For the case study analyses, we used a data set of Hospital *X* and it consists of patient information between January and June in the year 2019 as shown in Table 4.1.

	Ataşehir	**Beykoz**	**Çekmeköy**	**Kadıköy**	**Kartal**	**Maltepe**	**Pendik**	**Sancaktepe**	**Sultanbeyli**	**Tuzla**	**Ümraniye**	**Üsküdar**
January	14	8	4	32	12	12	4	6	2	8	20	10
February	14	8	7	25	12	1	6	8	2	6	15	12
March	14	4	6	25	6	16	1	4	2	7	20	16
April	12	8	6	21	3	8	1	2	3	7	24	15
May	8	7	6	24	4	12	6	4	2	6	14	16
June	10	2	5	26	14	12	4	3	3	5	14	15
Total	72	49	34	153	51	61	22	27	14	39	107	84

Table 4.1: The number of patients in each district between January and June in 2019.

25 operators are working in the HHC department of Hospital X and their district compatibility between January and June is shown in Table 4.2. For example, patients in Ataşehir district are visited by operator 1 and 2 or patients in the Üsküdar district are visited by operator 24 or 25.

	Ataşehir	**Beykoz**	**Çekmeköy**	**Kadıköy**	**Kartal**	**Maltepe**	**Pendik**	**Sancaktepe**	**Sultanbeyli**	**Tuzla**	**Ümraniye**	**Üsküdar**
1	1	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0	0
3	0	1	0	0	0	0	0	0	0	0	0	0
4	0	0	1	0	0	0	0	0	0	0	0	0
5	0	0	0	1	0	0	0	0	0	0	0	0
6	0	0	0	1	0	0	0	0	0	0	0	0
7	0	0	0	1	0	0	0	0	0	0	0	0
8	0	0	0	1	0	0	0	0	0	0	0	0
9	0	0	0	1	0	0	0	0	0	0	0	0
10	0	0	0	1	0	0	0	0	0	0	0	0
11	0	0	0	1	0	0	0	0	0	0	0	0
12	0	0	0	0	1	0	0	0	0	0	0	0
13	0	0	0	0	1	0	0	0	0	0	0	0
14	0	0	0	0	0	1	0	0	0	0	0	0
15	0	0	0	0	0	1	0	0	0	0	0	0
16	0	0	0	0	0	1	0	0	0	0	0	0
17	0	0	0	0	0	0	1	0	0	0	0	0
18	0	0	0	0	0	0	0	1	0	0	0	0
19	0	0	0	0	0	0	0	0	1	0	0	0
20	0	0	0	0	0	0	0	0	0	1	0	0
21	0	0	0	0	0	0	0	0	0	0	1	0
22	0	0	0	0	0	0	0	0	0	0	1	0
23	0	0	0	0	0	0	0	0	0	0	1	0
24	0	0	0	0	0	0	0	0	0	0	0	1
25	0	0	0	0	0	0	0	0	0	0	0	1

Table 4.2: Operator's district compatibility between January and June.

Patient-operator assignments are determined for a 3-month HHCS scheduling plan. As patient information between January and March is known beforehand, planning is done as static by using a developed deterministic mathematical model. Patients are assigned to operators considering the constraint of the operator's capacity and constraint of compatibility between patient and operators in the model. According to the results of the assignment as shown in Appendix section A, when the utilization of operators between January and March in 2019 as shown in Figure 4.1 is examined, it can be observed that the utilization of some operators such as operator 16 or 19 is below 50%. Also, the utilization of some operators is above 80% percent such as operator 1, 20, and 25.

The utilization of some operators may be seen as low the number of patients in the districts they serve is not sufficient. For instance, the utilization of operator 19 is 25%, and s/he visits all patients who live in Sultanbeyli but the number of patients in Sultanbeyli is 6 and the number of operators serving Sultanbeyli is 1 as shown in Table 4.3.

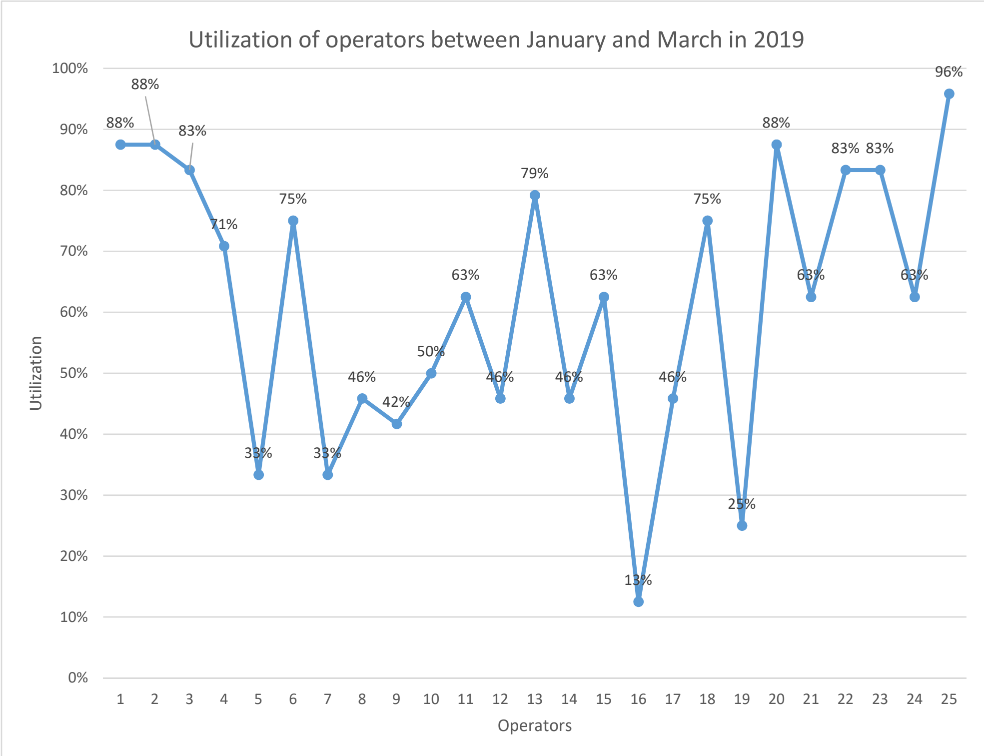

Figure 4.1: Utilization of operators between January and March in 2019.

Therefore, although the utilization of the district is 100% and all patients in that district receive care, the utilization of the operators working in that district is low. Moreover, when the results are analyzed in terms of continuity of care, it is observed that only two out of 369 patients received care from two different operators and all other patients are visited by the same operator. Patients with no continuity of care are shown in Table 4.4. According to Table 4.4 patient 363 who lives in Üsküdar is visited by operator 24 for 2 days and by operator 25 for 28 days. Patient 367 who lives in Üsküdar is visited by operator 24 for 28 days and by operator 25 for 2 days. When the number of days in the planning period, k is equal to 61, patient 363 and 367 are entered into the HHCS system and Üsküdar district is only served by the operator 24 and 25. The treatment process of these two patients is allocated among operator 24 and 25 because the model takes into account the workload balance among the operators as well as the continuity of care. Also, patient 363 and 367 cannot be assigned to the same operator as the number of patients to be visited by operator 24 and 25 is equal to 7 while k is 61.

j	Utilization	g	Number of j in district g	Number of i in g	Number of i in g served by j
1	88%	Ataşehir	2	42	21
2	88%	Ataşehir	2	42	21
3	83%	Beykoz	1	20	20
4	71%	Çekmeköy	1	17	17
5	33%	Kadıköy	7	82	8
6	75%	Kadıköy	7	82	18
7	33%	Kadıköy	7	82	8
8	46%	Kadıköy	7	82	11
9	42%	Kadıköy	7	82	10
10	50%	Kadıköy	7	82	12
11	63%	Kadıköy	7	82	15
12	46%	Kartal	2	30	11
13	79%	Kartal	2	30	19
14	46%	Maltepe	3	29	11
15	63%	Maltepe	3	29	15
16	13%	Maltepe	3	29	3
17	46%	Pendik	1	11	11
18	75%	Sancaktepe	1	18	18
19	25%	Sultanbeyli	1	6	6
20	88%	Tuzla	1	21	21
21	63%	Ümraniye	3	55	15
22	83%	Ümraniye	3	55	20
23	83%	Ümraniye	3	55	20
24	63%	Üsküdar	2	38	15
25	96%	Üsküdar	2	38	23

Table 4.3: Total number of patients served by operators between January and March in 2019.

Patient	District where the patient lives	Operator 24	Operator 25
Patient 363	Üsküdar	2 days	28 days
Patient 367	Üsküdar	28 days	2 days

Table 4.4: Patients with no continuity of care before between January and March in 2019.

After three months there is a job rotation among operators in Hospital X, operators cannot serve the same district for more than three months. The data of the new districts where operators will serve after rotation is shown in Table 4.5. For example, while operator 1 was working in Ataşehir before job rotation, operator 1 started to work in Üsküdar after the job rotation.

Then, we determined which operator will provide care service for which patient after rotation as shown in the appendix section B. According to the results of the assignment concerning rotation, when the utilization of operators between April and June in 2019 as shown in Figure 4.2, is examined, it can be observed that the utilization of some operators such as operator 18 or 19 is below 50% while the utilization of some operators is above 90% percent such as operator 1 or 2.

	District served by operator before rotation	District served by the operator after rotation
1	Ataşehir	Üsküdar
2	Ataşehir	Üsküdar
3	Beykoz	Ümraniye
4	Çekmeköy	Ümraniye
5	Kadıköy	Ümraniye
6	Kadıköy	Tuzla
7	Kadıköy	Sultanbeyli
8	Kadıköy	Sancaktepe
9	Kadıköy	Kartal
10	Kadıköy	Maltepe
11	Kadıköy	Maltepe
12	Kartal	Maltepe
13	Kartal	Pendik
14	Maltepe	Kartal
15	Maltepe	Kadıköy
16	Maltepe	Kadıköy
17	Pendik	Kadıköy
18	Sancaktepe	Kadıköy
19	Sultanbeyli	Kadıköy
20	Tuzla	Kadıköy
21	Ümraniye	Kadıköy
22	Ümraniye	Çekmeköy
23	Ümraniye	Beykoz
24	Üsküdar	Ataşehir
25	Üsküdar	Ataşehir

Table 4.5: Districts served by operators before and after job rotation.

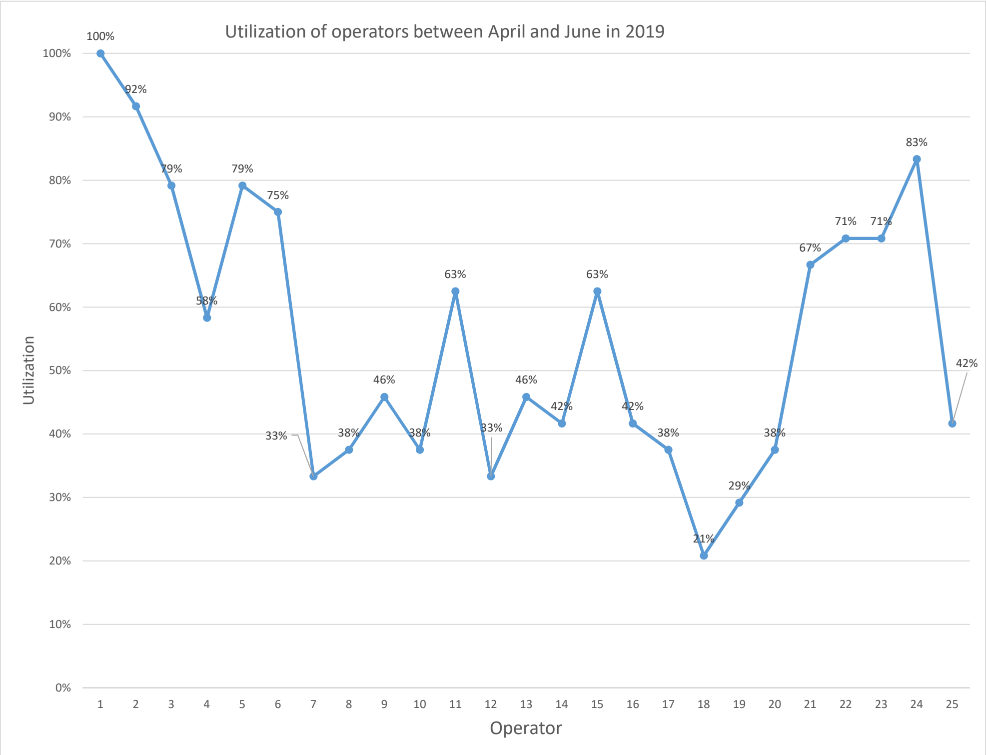

Figure 4.2: Utilization of operators between April and June in 2019.

The reason for the low utilization of operators after rotation, just like before rotation, is that Hospital X has just started to serve in HHCS and therefore there are not enough patient applications in each district where is served by Hospital X yet. Additionally, all patients in the system between April and June in 2019 receive care by the same operator during their treatment period and the continuity of care is provided as 100% after rotation. Also, the total number of patients served by operators between April and June in 2019 are shown in Table 4.6.

j	Utilization	g	Number of j in district g	Number of i in g	Number of i in g served by j
1	100%	Üsküdar	2	46	24
2	92%	Üsküdar	2	46	22
3	79%	Ümraniye	3	52	19
4	58%	Ümraniye	3	52	14
5	79%	Ümraniye	3	52	19
6	75%	Tuzla	1	18	18
7	33%	Sultanbeyli	1	8	8
8	38%	Sancaktepe	1	9	9
9	46%	Kartal	2	21	11
10	38%	Maltepe	3	32	9
11	63%	Maltepe	3	32	15
12	33%	Maltepe	3	32	8
13	46%	Pendik	1	11	11
14	42%	Kartal	2	21	10
15	63%	Kadıköy	7	71	15
16	42%	Kadıköy	7	71	10
17	38%	Kadıköy	7	71	9
18	21%	Kadıköy	7	71	5
19	29%	Kadıköy	7	71	7
20	38%	Kadıköy	7	71	9
21	67%	Kadıköy	7	71	16
22	71%	Çekmeköy	1	17	17
23	71%	Beykoz	1	17	17
24	83%	Ataşehir	2	30	20
25	42%	Ataşehir	2	30	10

Table 4.6: Total number of patients served by operators between April and June in 2019.

4.2 Computational results under different scenarios

The current patient density of the HHC scheduling system of Hospital X is low because there are not enough patient requests for HHCS to the hospital. It is desired to investigate how the continuity of care, workload balance, and utilization of the operators will change in the assignments when the patient density in the system increases. Hence, we generated scenarios based on the real data obtained from Hospital X and used the daily patient to operator ratio as a parameter in the scenarios. We considered different scenarios where an operator served one, two, or all preassigned districts. When the patient density and the number of districts served by the operators are increased, it is planned to observe the increase in the utilization of the operators, the workload balance and the percentage of patients receiving care by the same operator, and the decrease in the patient waiting time to receive care.

Firstly, random data for three different scenarios are generated in Excel. 100 different instances were produced for each patient to operator ratio of scenarios. In these scenarios, the workload density of operators is increased using different values of this patient to operator ratio ranging from 2 to 10 in multiples of 2. These patient density ratios can be considered as 2, 4, 6, 8, and 10 which means very low intensity, low intensity, medium intensity, high intensity, and very high intensity, respectively. This ratio is also used to determine the average daily number of patients in the system.

Scenario 1 is performed to evaluate the effects of change in the daily patient density ratio while all operators serve one district and scenario 2 is carried out to evaluate the effects of change in the daily patient density ratio while all operators serve 2 adjacent districts. Also, the effects of change in the daily patient density ratio while all operators serve all districts are observed in scenario 3.

In the experiments, all instances are generated by considering 25 operators (*J=25*) equaling the number of operators in the data of Hospital *X*, 100 days of planning horizon (*K=100*), 12 districts served by operators (*G=12*), the daily treatment capacity of operators a_{jk} equal to 8 patients. We assumed the daily operator capacity to be 8 patients and patients served are of the same type. Moreover, the care visit requirement of patient i in period k is provided by operator j, d_{ik} and the treatment duration required for each patient is 30 days meaning that once started each patient's treatment took 30 business days. If the care visit requirement of patient i in period k cannot be met, this care requirement is recreated to days later as much as the patient's remaining treatment day.

Although m_{jg} the compatibility between operator j and district g is determined in parameter settings, c_{ig} compatibility between patient i and district g is obtained from randomly generated instance data. The districts where the patients originated in the generated data were based on the real percentages in the data of hospital in 2019 for each district. Therefore, considering the average for 100 instances, it will be very close to the real percentage for districts of patients. For all scenarios, the number of patients is randomly generated according to the patient/operator ratio in Excel. The total number of patients in the system is calculated as follows:

Total number of patient in the system = *((the length of planning period)/(treatment period of patient))*(number of operator)*(patient/operator ratio)*

For example, for a patient/operator of 8, the length of planning period 100 days and the treatment period of patient of 30 days with 25 operators, the expected total number of patients in the system would be 667 patients. To generate data of scenarios for one month, we first chose the time horizon as 100 days and assumed that the arrivals of the patients to the system are made uniformly across the time horizon according to the proportion of patients in districts.

Also, we used a warm-up period to ensure that the number of patients in the generated data reaches the patient density levels corresponding to the set ratio. Since we consider our rolling period as 7 days, 30 optimizations are executed during the time horizon.

4.2.1 Results of scenario 1

In scenario 1, all operators are considered as serving only one district. Each ratio of scenario 1 is tested as a fixed and not-fixed model. All ratios of scenario 1 are run 100 times with fixing the operators on the first day of the treatment period of the patients and without fixing the operators.

The reason for conducting runs in this way is to measure the impact of assignments under continuity of care or continuity of care relaxation on workload balance and waiting times of patients.

For fixed models of all ratios in scenario 1, the percentage of receiving care from the same operator is 100% and the percentage of receiving care from the different operator is 0% as seen in Table 4.7 because the operators on the first day of the treatment period of the patients are fixed and they receive care from the same operator during their treatment period. In the table 4.7, the first column shows the patient/operator ratio. The second columns shows the daily average number of patients waiting to receive care. The third column shows the average patient waiting times to receive first care. The fourth column shows the average waiting time across all patients. The fifth, sixth, and seventh columns represent the percentage of patients receiving care from the same operator, the percentage of patients receiving care from the different operator, and the average max care percentage received from the same operator, respectively.

As shown in Table 4.7, patients do not wait a long time for starting to receive care and their treatments are started immediately when the patient/operator ratio is 2 and 4.

No patient is waiting to receive care during the planning period while the ratio is 2 and 4. Since the patient density in the system increased to 6, 8, and 10 the daily average number of patients waiting to receive care, average patient waiting times to receive first care, and average waiting time across all patients started to increase because of increased the number of patients in the system and workload of operators. When the ratio is 10, there is a significant increase in the daily average number of patients waiting to receive care was observed as the daily patient visit capacity of operators is eight patients. After the ratio is 6, the new patients are assigned to the dummy operator and they wait to receive care as the capacity of all operators in the system is full. Also, the patients start to wait an average of two days to receive service when the ratio is 8.

Pat/Op Ratio	**# of Pat Waiting**	**Days to First Care**	**Tot. Waiting**	**Same Op (%)**	**Diff. Op (%)**	**Same Op Max (%)**
2	0	0	0	100	0	100
4	0	0	2	100	0	100
6	4	0	5	100	0	100
8	28	2	7	100	0	100
10	89	5	10	100	0	100

Table 4.7: Results of fixed models in scenario 1.

For the not-fixed model of all ratios in scenario 1, the percentage of receiving care from the same operator is above 98% percent. Although patients are allowed to receive care from different operators in the not-fixed model, it had an impact on the continuity of care almost negligible. When we examine the results of the not-fixed models of scenario 1, it can be observed that compared to the fixed model of scenario 1 as the patient density increases, the number of patients waiting for treatment increases but the waiting times of the patients decrease in Table 4.8. In not-fixed models, patients can be visited by more than one operator. Since patients can be visited by more than one operator, the patient's waiting to receive care is reduced. To ensure continuity of care for patients, the model chose to reduce the total waiting time of the patients by conceding the average patient waiting times to receive first care compared to the fixed model.

Pat/Op Ratio	# of Pat Waiting	Days to First Care	Tot. Waiting	Same Op (%)	Diff. Op (%)	Same Op Max (%)
2	0	0	0	98	2	100
4	0	0	0	99	1	100
6	4	6	1	99	1	100
8	28	37	3	99	1	100
10	89	108	7	100	0	100

Table 4.8: Results of not-fixed models in scenario 1.

The district utilization of fixed and not-fixed models in scenario 1 are depicted in Figure 4.3 and 4.4, respectively. The horizontal axis of the figure denotes districts and the vertical axis denotes the percentage of the utilization. As the patient density increases, the utilization in all districts starts to decrease depending on the number of patients who could not be treated. However, even when the patient density is at the highest level, the district utilization is observed to be the lowest 80% percent. With ratio is 8, the number of patients waiting to receive care in districts has increased since operators have no capacity to visit new patients.

Also, the utilization percentage in the districts is not changed by fixing the operators in the scenarios. As the number of patients treated is not affected by solving the model without fixing the operators and only continuity of care is affected by fixing operators, the number of patients treated in districts is not changed.

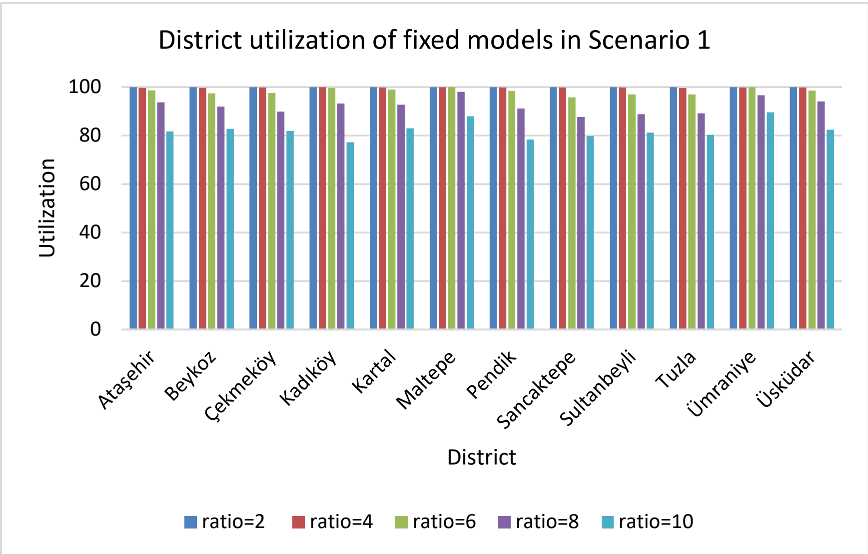

Figure 4.3: District utilization of fixed models in scenario 1.

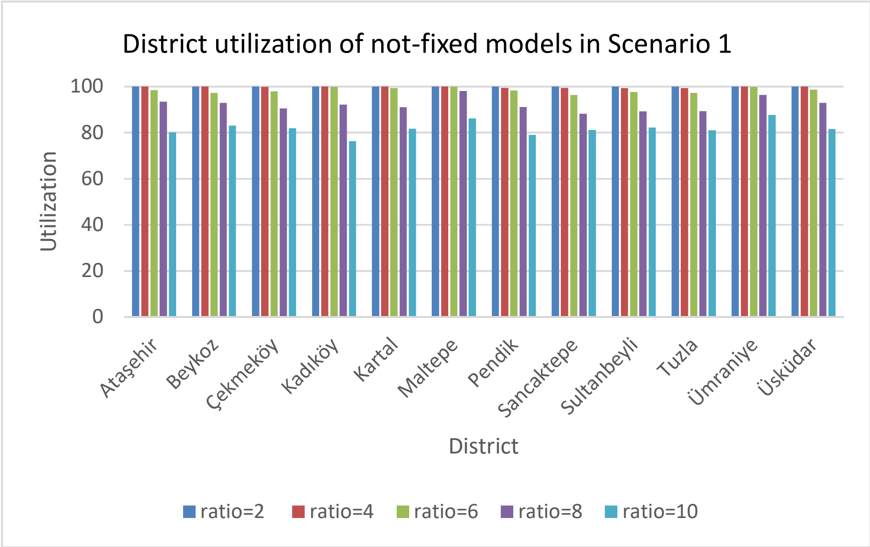

Figure 4.4: District utilization of not-fixed models in scenario 1.

In addition to the utilization of districts, the efficiency of the operators was examined in the analyses. The operator utilization in the fixed and not-fixed models of scenario 1 presented in Figure 4.5 and Figure 4.6. The horizontal axis of the figure denotes operators and the vertical axis denotes the percentage of the utilization. It can be observed that as the patient density in the system increases, the number of patients visited by operators increases, and therefore the utilization of operators increases.

As shown in Figure 4.5, the utilization of some operators in the fixed model is higher than in others. For instance, the utilization of *operator 5* is higher than *operator 2*'s. *Operator 5* serves patients in Kadıköy district and *operator 2* serves patients in Ataşehir district. The reason for the difference between the utilization of these two operators is that the patient density in Kadıköy district is higher than in Ataşehir district. As the number of patients in Kadıköy district is higher than in Ataşehir district, compared to *operator 2* more patients are visited by *operator 5*. Thus, the utilization of *operator 5* is higher than *operator 2*'s.

Moreover, the utilization of operators is affected by fixing the operators in the scenarios. As seen in Figure 4.6 some of the operators have visited more patients in the not-fixed models, as patients can receive care from more than one operator.

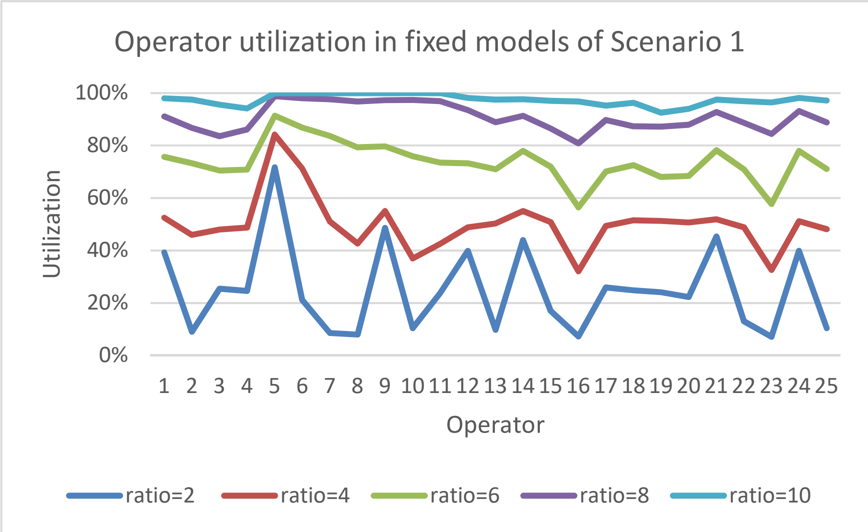

Figure 4.5: Operator utilization of fixed models in scenario 1.

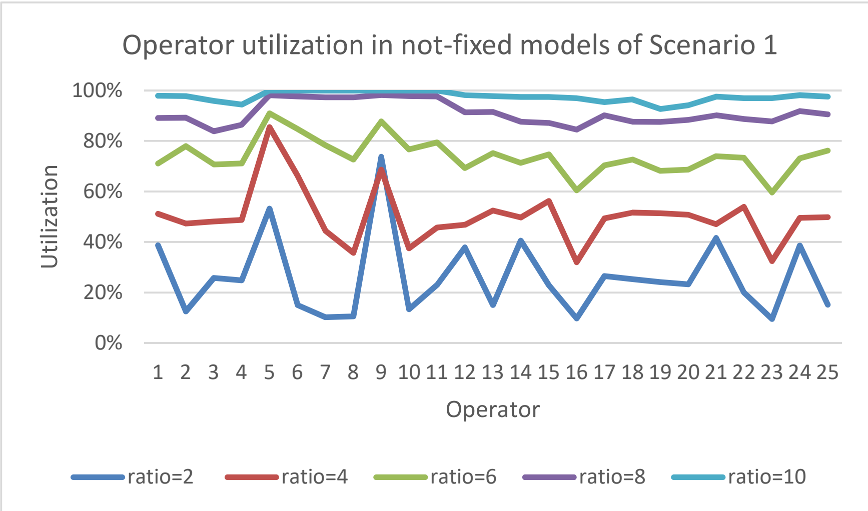

Figure 4.6: Operator utilization of not-fixed models in scenario 1.

4.2.2 Results of scenario 2

While all operators are considered as serving only one district in scenario 1, all operators are considered as serving two adjacent districts in scenario 2.

For fixed models of all ratios in scenario 2, the percentage of receiving care from the same operator is 100% and the percentage of receiving care from the different operator is 0% as seen in Table 4.9 because the operators on the first day of the treatment period of the patients are fixed and they receive care from the same operator during their treatment period.

Pat/Op Ratio	# of Pat Waiting	Days to First Care	Tot Waiting	Same Op (%)	Diff. Op (%)	Serving 1 dist. (%)	Serving 2 dist. (%)
2	0	0	0	100	0	30%	70%
4	0	0	1	100	0	6%	94%
6	1	0	3	100	0	3%	97%
8	12	1	4	100	0	2%	98%
10	87	5	9	100	0	2%	98%

Table 4.9: Results of fixed models in scenario 2.

Table 4.9 shows that the daily number of patients waiting to receive care, patient waiting times to receive first care, and waiting times of the patients have decreased significantly when the ratio is 6 and 8 compare to scenario 1. Increasing the number of districts operators serve decreases patient waiting times since an operator can attend patients from other districts when available. The reason for this decrease is that operators also serve the district closest to them (2 districts in total) in scenario 2. Even with a ratio is equal to 10 where the patient density is the highest, there is a slight decrease in the daily number of patients waiting to receive care, patient waiting times to receive first care and waiting times of the patients. Moreover, the percentage of operators serving two districts is increased with the patient density ratio is 4. For the not-fixed model of all ratios in scenario 2, the percentage of receiving care from the same operator is above 95% percent as presented in Table 4.10. The reason for the negligible impact on continuity care is that operators can visit more patients by working in two districts. When we examine the results of the not-fixed models of scenario 2, it can be observed that as the patient density increases, the number of patients waiting for treatment increases, but the waiting times of the patients decreases in comparison to the fixed model of scenario 2.

Although there is not a very big difference, it was observed that the average waiting time of all patients in the not-fixed models in scenario 2 was lower than the fixed models of scenario 2. The average waiting times of all patients in the system have decreased since patients can receive services from different operators in not-fixed models. However, not fixing the operators did not affect the patients waiting time to receive first care. The patients waiting time to receive first care did not decrease in the not-fixed model, as patient entries into the system continue daily and the treatment period of existing patients continues during 30 days.

Pat/Op Ratio	# of Pat Waiting	Days to First Care	Tot Waiting	Same Op (%)	Diff. Op (%)	Serving 1 dist. (%)	Serving 2 dist. (%)
2	0	0	0	96	4	27%	73%
4	0	0	0	96	4	5%	95%
6	1	0	2	95	5	3%	97%
8	15	1	3	95	5	2%	98%
10	99	6	6	100	0	4%	97%

Table 4.10: Results of not-fixed models in scenario 2.

When the utilization of the districts is examined, it can be observed that the utilization of districts is almost 100% for all patient/operator ratios except the ratio is equal to 10 as shown in Figure 4.7. For the ratio is equal to 10, the utilization is around 80% among districts because the number of patients who cannot start to receive care due to the increase in the patient density increases.

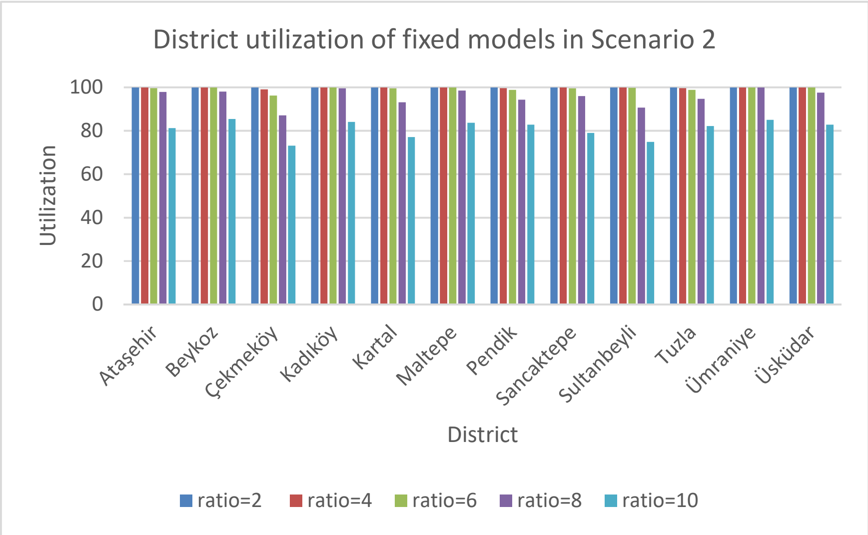

Figure 4.7: District utilization of fixed models in scenario 2.

District utilization of not-fixed models in scenario 2 is illustrated in Figure 4.8. When Figure 4.7 and Figure 4.8 are examined, it can be found that there is no significant difference between the district utilization of fixed and not-fixed models in scenario 2 because the number of patients in the districts does not change when the not-fixed model is run. Solving the model without fixing the operators affects patients waiting time to receive care and continuity of care but the number of patients treated is the same in both models.

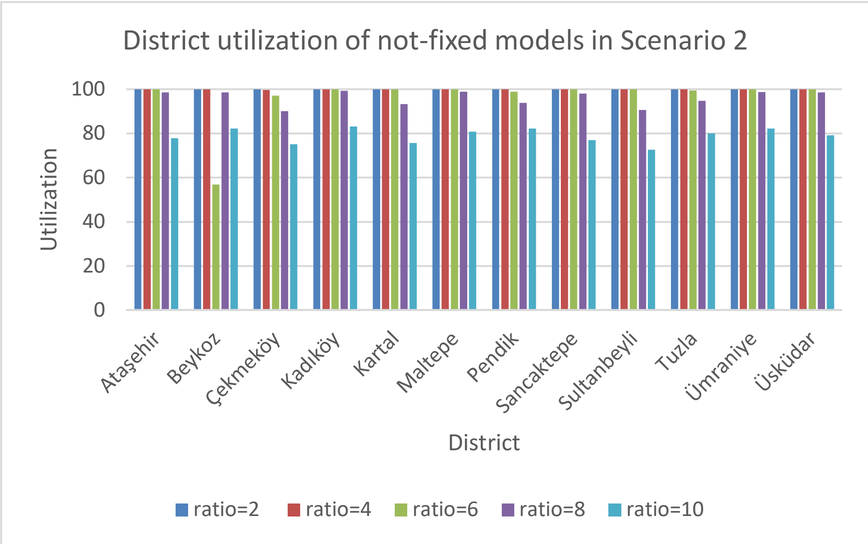

Figure 4.8: District utilization of not-fixed models in scenario 2.

Besides the utilization of districts, the efficiency of the operators was examined in the analysis. The operator utilization in the fixed and not-fixed models in scenario 2 is presented in Figure 4.9 and Figure 4.10. According to Figure 4.9 and Figure 4.10, the utilization of the operators is around 25%, 50%, 75%, 95%, and 100% when the ratio is equal to 2, 4, 6, 8, and 10 respectively. The reason for this growth is an increase in the number of patients in the system. Operators use their capacity more as the patient/operator ratio increases depending on the number of patients in the district where they serve.

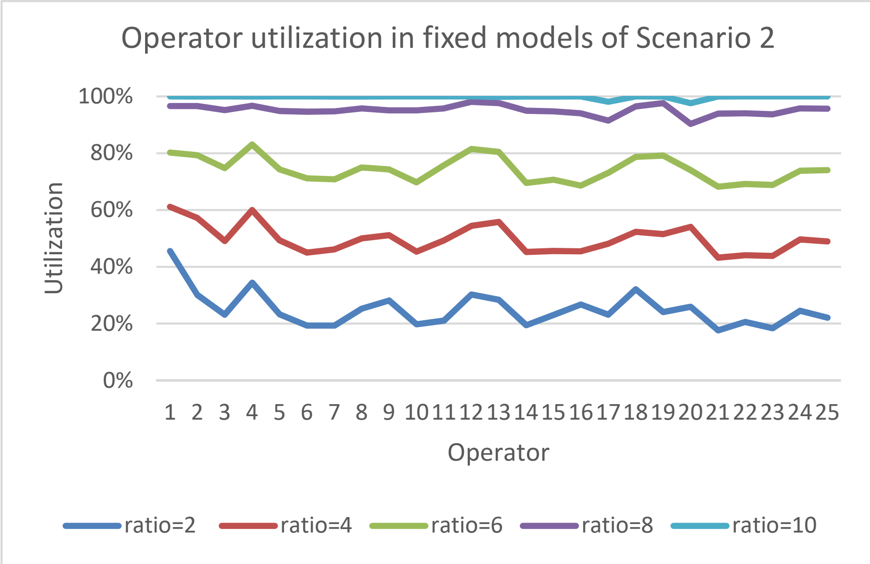

Figure 4.9: Operator utilization of fixed models in scenario 2.

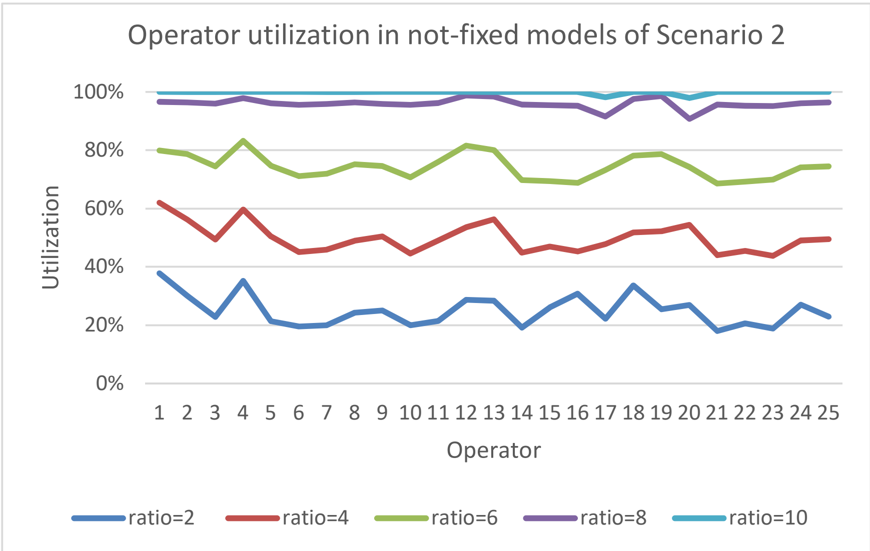

Figure 4.10: Operator utilization of not-fixed models in scenario 2.

4.2.3 Results of scenario 3

Operators provide service to patients in one district in scenario 1, in two districts in scenario 2, and each district in scenario 3. The results of scenario 3 is affected by the operators' ability to visit patients in each district.

According to Table 4.11, it can be observed that while the ratio is 2 or 4, the percentage of operators serving in more than 3 districts is not very high like 34% but for the ratio is 6 and above, all operators reduce the number of patients waiting to receive care, patient waiting time to receive first care, and total waiting time of all patients by serving patients in more than 3 districts. When all ratios of scenario 3 for the fixed model are analyzed in terms of the continuity of care, it can be seen that the percentage of receiving care from the same operator is 100% and the percentage of receiving care from the different operator is 0% as shown in Table 4.11 because the operators on the first day of the treatment period of the patients are fixed and they receive care from the same operator during their treatment period.

Pat/Op Ratio	# of Pat Waiting	Days to First Care	Tot Waiting	Same Op (%)	Diff. Op (%)	Serving 1 dist.(%)	Serving 2 dist.(%)	Serving 3+ dist.(%)
2	0	0	0	100	0	2%	20%	34%
4	0	0	0	100	0	0%	1%	94%
6	0	0	0	100	0	0%	0%	99%
8	7	0	2	100	0	0%	0%	100%
10	92	6	9	100	0	0%	0%	100%

Table 4.11: Results of fixed models in scenario 3.

According to Table 4.12, although the operators are not fixed, the continuity of care is affected in a small percentage and even at the ratio is equal to 10 where the model is forced in terms of patient density. The number of patients receiving care from different operators is almost zero. Also, the number of patients waiting to receive care, patient waiting time to receive first care, and the total waiting time of all patients are decreased in not-fixed model results of scenario 3. The reason for this decrease is that patients in any district can be served by any operator in the not-fixed models of scenario 3. As the operators in scenario 3 can serve every district, while the ratio is equal to 6 no patients are waiting to receive care in the system, and the patient waiting time to receive care is zero. Like the results in scenario 2, it was observed that the average waiting time of all patients in the not-fixed models in scenario 3 was lower than the fixed models of scenario 3. The average waiting times of all patients in the system have decreased since patients can receive services from different operators in not-fixed models. However, not fixing the operators did not affect the patients waiting time to receive first care.

Pat/Op Ratio	# of Pat Waiting	Days to First Care	Tot Waiting	Same Op (%)	Diff. Op (%)	Serving 1 dist.(%)	Serving 2 dist.(%)	Serving 3+ dist.(%)
2	0	0	0	97	3	2%	17%	37%
4	0	0	0	98	2	0%	0%	94%
6	0	0	0	99	1	0%	0%	100%
8	11	1	1	98	2	0%	0%	100%
10	100	6	6	100	0	0%	0%	100%

Table 4.12: Results of not-fixed models in scenario 3.

When the utilization of the districts is examined that in scenario 1 and scenario 2, the utilization of the districts is 100% only at the ratio is equal to 2 and 4 however in scenario 3 even at the ratio is equal to 8, almost 100% as each operator serves each district as seen in Figure 4.11 and Figure 4.12.

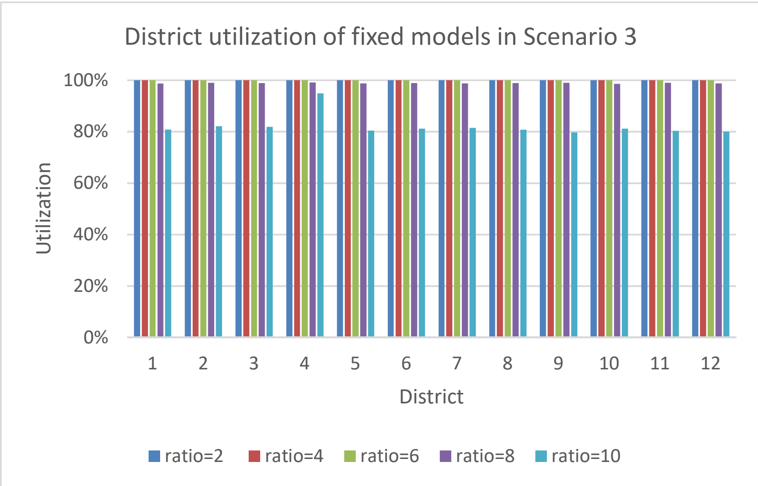

Figure 4.11: District utilization of fixed models in scenario 3.

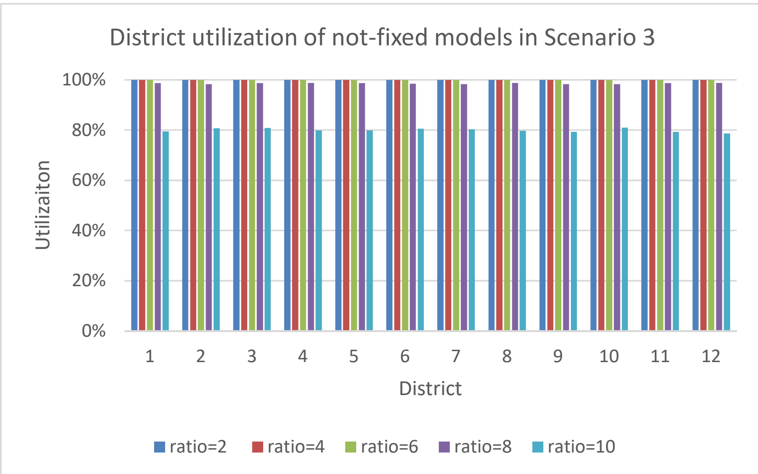

Figure 4.12: District utilization of not-fixed models in scenario 3.

Lastly, the efficiency of the operators in scenario 3 is examined in the analyses. The operator utilization in the fixed and not-fixed models in scenario 3 is presented in Figure 4.13 and Figure 4.14. According to Figure 4.13 and Figure 4.14, it can be observed that the utilization of fluctuation among operators is decreased for every ratio and continued constantly. Moreover, the utilization of operators is reached 100% completely for the ratio is equal to 8 and 10.

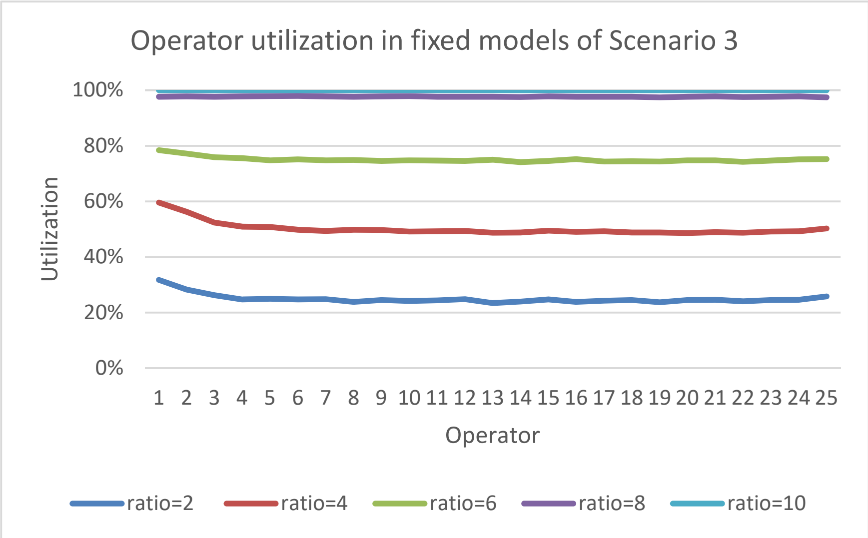

Figure 4.13: Operator utilization of fixed models in scenario 3.

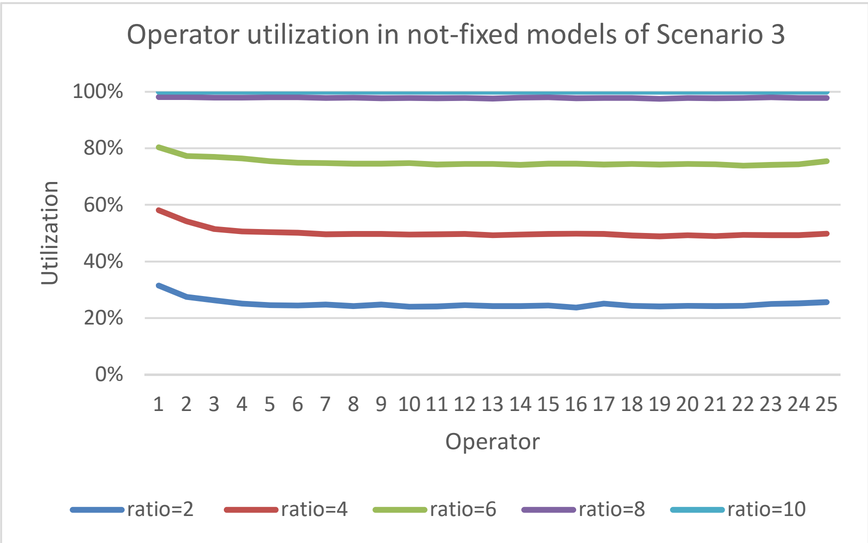

Figure 4.14: Operator utilization of not-fixed models in scenario 3.

4.3 Sensitivity analysis for multi objectives in the model

In this section, weights for objectives in the model are explained and adjusted to help the decision-makers. The selection of weights influences assignment results. The weight coefficient of the first objective function is chosen as a negative number because the operator's workload balance is ensured by the first objective of the model. The selected negative weight coefficient maximizes the value of the first objective function while minimizing the value of the other objectives. In other words, workload balance is provided with max-min function at the first objective function term. On the other hand, the assignment of patients to the dummy operator is minimized at the third objective function. The weight coefficient of the third objective function is chosen as a big positive number as patients should not be assigned to the dummy operator. Therefore, the changes in the weight coefficients of objective function terms other than these two objective function terms are examined. Although the best results are obtained in scenario 3, the applicability of scenario 2 is more realistic compared to other scenarios. Thus, scenario 2 is selected as a reference to examine the effect of weight selection on the assignment results.

This analysis is performed for fixed and not-fixed models of scenario 2 while the number of the operator is equal to 25, the planning period is 30 days, and the patient density ratio is 8. Initially, weight coefficients of objective functions are set as -10, 10, 1000, 1, and 1 respectively. Then, weights are updated and results are recorded in Table 4.13 and 4.14. When the results are examined, it can be observed that the results of the not-fixed model are better than the results of the fixed model as seen in Table 4.14. When continuity of care has a high priority for the decision-maker, any weight set of a fixed model or second weight set of the not-fixed model can be used. If the total waiting time of all patients has higher importance than other criteria, the first and second weight set of a fixed model or third weight set of a not-fixed model can be selected by the decision-maker. For other criteria, using the second weight set leads to better results.

	Min(Z1+Z2+Z3+Z4+Z5)				
	(-10,10,1000,1,1)	**(-10,10,1000,1,10)**	**(-10,10,1000,10,1)**	**(-10,10,1000,10,10)**	**(-10,1,1000,1,1)**
Number of Pat. Waiting	4,80	5,57	5,93	6,03	6,17
Days to First Care	0,38	0,44	0,47	0,48	0,49
Total waiting time	2,00	2,39	2,31	2,26	2,08
Same Op (%)	100	100	100	100	100
Diff. Op (%)	0	0	0	0	0
Serving only 1 dist. (%)	0%	0%	0%	0%	0%
Serving 2 dist. (%)	100%	100%	100%	100%	100%

Table 4.13: Sensitivity analysis for fixed model of scenario 2.

	Min(Z1+Z2+Z3+Z4+Z5)				
	(-10,10,1000,1,1)	**(-10,10,1000,1,10)**	**(-10,10,1000,10,1)**	**(-10,10,1000,10,10)**	**(-10,1,1000,1,1)**
Number of Pat. Waiting	7,27	5,57	5,93	6,03	6,17
Days to First Care	0,38	0,44	0,47	0,48	0,49
Total waiting time	2,00	2,39	2,31	2,26	2,08
Same Op (%)	100	100	100	100	100
Diff. Op (%)	0	0	0	0	0
Serving only 1 dist. (%)	0%	0%	0%	0%	0%
Serving 2 dist. (%)	100%	100%	100%	100%	100%

Table 4.14: Sensitivity analysis for not-fixed model of scenario 2.

Chapter 5

Conclusion and Future Works

In this thesis, we provided a framework for the HHCS patient assignment system of physiotherapy and rehabilitation Hospital, Hospital X. This framework based on a two-stage solution approach; in the first stage, the assignment is made considering the compatibility constraint of patients and operators by developed an integer linear model which aims to provide the continuity of care, balance the operator workload, and while keeping patient waiting times low. In the second stage; for operators, job rotation that is requested from Hospital X is performed considering created patient-operator assignments in the first stage. After the second stage, model results were compared with 5 different patient density ratios under three scenarios. In these scenarios, the workload density of operators is increased using different daily patient/operator ratio with generated random 100 instance data set and all ratios of scenarios are run with fixing the operators on the first day of the treatment period of the patients and without fixing the operators to measure the impact of assignments under continuity of care or continuity of care relaxation on workload balance and waiting times of patients. Firstly, scenario 1 is applied to evaluate the effects of change in the daily patient/operator ratio while all operators serve one district. Secondly, scenario 2 is carried out to evaluate the effects of change in the daily patient/operator ratio while all operators also serve their closest 2 districts in total. Lastly, scenario 3 is performed to analyze the effects of change in the daily patient/operator ratio while all operators serve all districts by using a rolling horizon approach.

The assignment results of the case study showed that although the utilization of the districts served by operators is 100% and all patients in these districts receive care, the utilization of the operators working in that districts can appear low. The reason why operators' utilization appears low is that Hospital X has just started to serve in HHCS and so there are not enough patient applications in each district where is served by Hospital X yet. As HHCS for Hospital X is a newly developing system, we designed scenarios to test the performance of the model and analyzed their results. According to the results of scenarios, the percentage of receiving care from the same operator is 100% and the percentage of receiving care from the different operators is 0% so, they receive care from the same operator during their treatment period for fixed models of all ratios and scenarios. When not-fixed models of the scenarios are examined in terms of continuity of care, although patients are allowed to receive care from different operators in the not-fixed model, it had an impact on the continuity of care almost negligible. The daily number of patients waiting to receive care, patient waiting times to receive first care, and waiting times of the patients in scenario 2 decrease significantly compare to scenario 1 because operators also serve the district closest to them in scenario 2. In scenario 3, there is no number of patients waiting to receive care in the system and the new patient does not wait to receive treatment until the operators work at full capacity. When we examine the results of the not-fixed models, it can be observed that as the patient density increases, the number of patients waiting for treatment increases, but the waiting times of the patients decreases in all fixed models for each scenario. Results also showed that limiting the districts operators serve increases patient waiting times since an operator cannot attend patients from other districts even when available.

Any scenario can be chosen to ensure continuity of care, as the continuity of care ratio is provided above 95% in all scenarios when all scenarios are compared. However, some parameters such as the number of patients waiting to receive care, patient waiting time to receive first care, and the total waiting time of all patients can result in differences in the scenarios.

In all scenarios, while the patient density ratio is 2 and 4 no patients are waiting to receive care in the system, and the patient waiting time to receive care and total waiting time of all patients is zero. However, if the patient density is the highest as 8 or 10, more desirable results are obtained in scenario 2 and scenario 3 compared to scenario 1. Although the best results are obtained in scenario 3, the applicability of scenario 2 is more realistic compared to other scenarios. Thus, scenario 2 should be chosen by the decision-maker. Therefore, the developed model was shown to perform well by using rolling horizon algorithm.

For future research, variability in the number of operators during the planning period will add a different dimension to the problem. In this study, it is assumed that the number of operators does not change during the planning period. However, home health care is a dynamic process. While new operators may be included in the system, some of the existing operators may leave their jobs. Another future research direction could be cost comparisons. The developed model does not contain any cost related objective, currently. Cost comparisons can also be made in scenarios with future information. Moreover, all patients are considered as same type in the model, currently. In the future work, we can add a new parameter to the model for compatibility between operators and patient type. Besides, determining the daily routing of visits for operators in the system. Finally, the model can be modified according to the operators visiting patients using vehicles or public transportation. Operators using public transportation can be assigned to patients at a short distance, and operators driving vehicles can be assigned to patients at long distances.

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Appendices

Appendix A

Assignment Results of Case Study Before Rotation

Total number of visits of patient i by operator j	**Operator**																									
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
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Table A.1: Assignment Results of Case Study Before Rotation.

Total number of visits of patient i by operator j	**Operator**																									
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
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Table A.2: Assignment Results of Case Study Before Rotation (Continued)...

Total number of visits of patient i by operator j	**Operator**																									
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
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Table A.3: Assignment Results of Case Study Before Rotation (Continued 2)...

Total number of visits of patient i by operator j	Operator																									
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
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258	30																									30
259	30																									30
260		30																								30

Table A.4: Assignment Results of Case Study Before Rotation (Continued 3)...

Total number of visits of patient i by operator j	Operator																									
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
261		30																								30
262	30																									30
263			30																							30
264			30																							30
265			30																							30
266			30																							30
267				30																						30
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271				30																						30
272				30																						30
273											30															30
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276							30																			30
277										30																30
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323																		30								30
324																		30								30
325																			30							30
326																			30							30
327																				30						30
328																				30						30
329																				30						30
330																				30						30

Table A.5: Assignment Results of Case Study Before Rotation (Continued 4)...

Total number of visits of patient i by operator j	**Operator**																									
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
331																				30						30
332																				30						30
333																				30						30
334																					30					30
335																							30			30
336																							30			30
337																							30			30
338																							30			30
339																							30			30
340																							30			30
341																							30			30
342																						30				30
343																						30				30
344																						30				30
345																						30				30
346																						30				30
347																							30			30
348																						30				30
349																					30					30
350																					30					30
351																					30					30
352																					30					30
353																					30					30
354																								30		30
355																								30		30
356																								30		30
357																									30	30
358																								30		30
359																								30		30
360																									30	30
361																								30		30
362																									30	30
363																								2	28	30
364																									30	30
365																								30		30
366																									30	30
367																								28	2	30
368																									30	30
369																									30	30

Table A.6: Assignment Results of Case Study Before Rotation (Continued 5)...

Appendix B

Assignment Results of Case Study After Rotation

Total number of visits of patient i by operator j	**Operator**																									
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
1																								30		30
2																								30		30
3																								30		30
4																								30		30
5																									30	30
6																								30		30
7																								30		30
8																									30	30
9																									30	30
10																									30	30
11																								30		30
12																								30		30
13																							30			30
14																							30			30
15																							30			30
16																							30			30
17																							30			30
18																							30			30
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21																						30				30
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26																						30				30
27																	30									30
28																		30								30
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31																30										30
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37															30											30
38																	30									30
39															30											30
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41															30											30
42																					30					30
43															30											30
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45																					30					30
46																				30						30
47																			30							30
48														30												30
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61								30																		30
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64							30																			30
65						30																				30
66						30																				30
67						30																				30
68						30																				30
69						30																				30
70						30																				30

Table B.1: Assignment Results of Case Study After Rotation.

Total number of visits of patient i by operator j	Operator																									
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
71						30																				30
72				30																						30
73				30																						30
74			30																							30
75			30																							30
76					30																					30
77					30																					30
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81				30																						30
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87					30																					30
88				30																						30
89			30																							30
90					30																					30
91			30																							30
92			30																							30
93				30																						30
94			30																							30
95			30																							30
96		30																								30
97		30																								30
98		30																								30
99	30																									30
100	30																									30
101	30																									30
102		30																								30
103		30																								30
104		30																								30
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106	30																									30
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114																								30		30
115																								30		30
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117																								30		30
118																									30	30
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131																						30				30
132															30											30
133															30											30
134															30											30
135																					30					30
136																				30						30
137																					30					30
138																					30					30
139																	30									30
140																					30					30

Table B.2: Assignment Results of Case Study After Rotation (Continued)...

Total number of visits of patient i by operator j	**Operator**																								
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
141																					30						30
142																				30							30
143																				30							30
144																	30										30
145																	30										30
146																		30									30
147																						30					30
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151																		30									30
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204	30																										30
205		30																									30
206	30																										30
207	30																										30
208		30																									30
209		30																									30
210		30																									30

Table B.3: Assignment Results of Case Study After Rotation (Continued 2)...

Total number of visits of patient i by operator j	Operator																								
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
211		30																								30
212		30																								30
213		30																								30
214	30																									30
215	30																									30
216	30																									30
217	30																									30
218	30																									30
219		30																								30
220																								30		30
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273									30																	30
274									30																	30
275														30												30
276														30												30
277										30																30
278												30														30
279										30																30
280											30															30

Table B.4: Assignment Results of Case Study After Rotation (Continued 3)...

Total number of visits of patient i by operator j	Operator																									
Patient	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**Total**
281										30																30
282											30															30
283										30																30
284											30															30
285												30														30
286											30															30
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324	30																									30
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326		30																								30
327	30																									30
328		30																								30
329	30																									30
330	30																									30
331	30																									30
332	30																									30

Table B.5: Assignment Results of Case Study After Rotation (Continued 4)...