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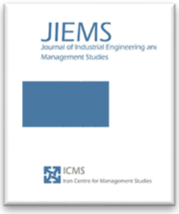

Multi-period Service Scheduling with Consideration of Customer Preferences

Setareh Boshrouei Shargh [1], Mostafa Zandieh*[1], Ashkan Ayough[1]

[1] Industrial Management Department, Faculty of Management & Accounting, Shahid Beheshti University, Tehran, Iran.

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Abstract

The operations management in service organizations has become a significant focus for researchers and decision-makers in recent years. Accordingly, scheduling problems, which are the process of allocating resources within a specific planning horizon, are a fundamental aspect of every service system. Corporations need to satisfy some recurring service requirements in such systems where the efficient allocation of resources and effective time management are vital for improving operational processes. This problem, known as multi-period service scheduling, includes customers with periodic demands for specific services. By investigating the related study, no research has been found that surveyed the different visit patterns of customers. Thereby, this is the first study to provide a mathematical model that takes into account customers' preferences concerning various different visit patterns. Despite its complicated structure, the problem is formulated as a new Pure Integer Linear Programming (PILP), minimizing the total number of operators required during the planning horizon. This study uses a numerical example and a real case study to confirm the validity of the proposed model. The practical implications of this research are significant, as it presents a model that can effectively solve real-world, large-scale problems with reasonable computing time and full compliance with all constraints, thereby improving operational efficiency and customers satisfaction.

Keywords: Scheduling, Service Systems, Multi-period Problems, Optimization, Preferences

Paper Type: Original Research

1. Introduction

In the current dynamic and fiercely competitive business environment, companies always seek strategies to maximize their resources, boost efficiency, and stay agile in the face of evolving market needs (Choi & Yang, 2024; Handoyo et al., 2023). Accordingly, effective resource allocation management, efficient scheduling, and sequencing are now essential to thrive in the current competitive environment. The manufacturing and service sectors make extensive use of scheduling, which entails assigning personnel to complete tasks within a specific time frame while taking into account various operational restrictions such as capacity, due dates, cancellations, priority, availability (Pinedo, 2012). Over the past thirty years, the services sector has grown more rapidly than the industrial sector in numerous economies. In recent years, a global trend has been among developed countries to transition their economies from manufacturing to service sectors (Hofmeister et al., 2023). Service industries account for the vast majority of the world's GDP in terms of value-added (Witt & Gross, 2020). According to Figure 1, the added value of the service sector to the global GDP through 28 years has increased over time. As stated by Statista (www.statista.com), the services sector accounted for around 77.6 percent of the United States GDP in 2021, contributed over 1.84 trillion U.S. dollars to the GDP. Thus, it is not unexpected that researchers have recently displayed significant interest in service operations management due to the growing significance of service sectors in the global economy.

*Corresponding Author: m_zandieh@sbu.ac.ir

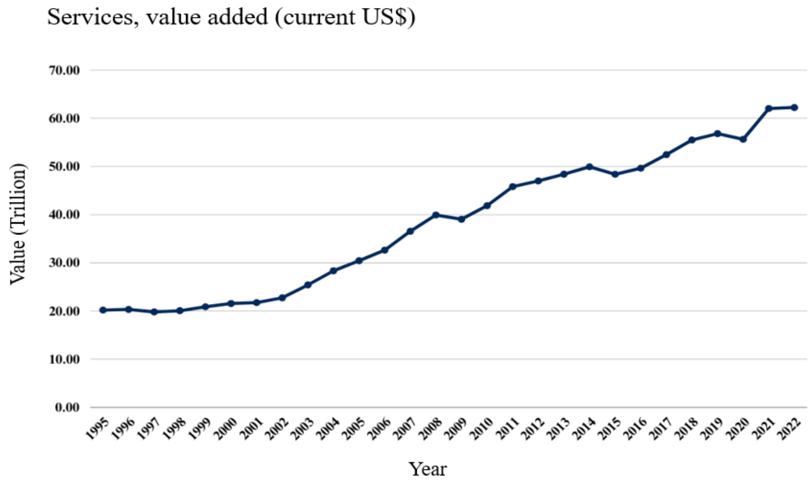

Figure 1. Value added to GDP by service industry 1995-2022, World Bank National Accounts Data.

In many service systems, various situations exist where resources are utilized to meet specific recurring demand requirements over a planning horizon. In these systems, a group of customers repeatedly requests a particular service during a specific and scheduled period. These service requests, which could involve delivery, maintenance, or collection, are the tangible manifestations of these services (Bender, 2017; Phusingha, 2021). In these problems, known as multi-period scheduling problems, the objective is to establish the most efficient allocation of operators to each customer throughout the planning horizon (Naser Sadrabadi et al., 2020). Previous published studies have developed models to address the multi-period service scheduling problems. The majority of papers focus on either establishing solution methods and algorithms or developing models that consider each problem's unique aspects. However, a crucial aspect that has been overlooked is the customers' preferences in the referral pattern throughout the planning horizon. Customers may exhibit varying preferences for visit times during the planning horizon in numerous real-world scenarios. While previous studies have shed light on mathematical modeling techniques for considering customer preferences in scheduling decisions, taking into account waiting costs, service quality, and uncertainty, they ignored customers' priorities and varied preference patterns over the planning horizon. Our efforts are driven by the need to develop a mathematical model for multi-period service scheduling problems that consider consumers' various visit pattern preferences. This is one of the initial studies in this area. Consequently, the novel structure of the model is expected to capture the attention of the academic community. The rest of our paper is according as follows. In Section 2, we provide a comprehensive review of previous research on the relevant topic. Section 3 then presents the problem description and the mathematical model. Section 4 discusses the effectiveness of the proposed model through a numerical experimentation and a real case study. We also present sensitivity analyses of the key parameters of the proposed model. The managerial insights of this study are expressed in Section 5. Finally, the findings and future directions are presented in Section 6.

2. Literature Review

In this section, we review studies that consider customer preferences in their suggested models, as well as studies that have examined the practical implications of multi-period service scheduling problems.

2.1. Service Scheduling Problems

According to (Boshrouei Shargh et al., 2024), when regarding the scheduling of service systems, there are several related problems in the literature, such as vehicle routing problems (Wang et al., 2024), appointment scheduling (Vali-Siar et al., 2018), berth scheduling (Guo et al., 2021), personnel scheduling (Guastaroba et al., 2021), and maintenance scheduling (Jafar-Zanjani et al., 2022). Multi-period characteristics of services can be found in each of these problems. For example, logistics, which includes collecting and delivering goods, raw resources, or waste, is a prime example of multi-period service problems. In these scenarios, there is a fixed rate of production or consumption every time, and customers have a finite storage space. This necessitates the availability of a suitable vehicle for periodic customer collections and deliveries and for transporting goods to and from other facilities like warehouses, factories, or recycling centers. The aim is to minimize the required tours while adhering to each customer's storage limitations. This is achieved by determining the optimal hours for servicing each customer (Núñez-del-Toro et al., 2016). One example of this context is the vital operational activity of organizing the cleaning staff members, which must be conducted regularly. This activity is essential in hospitals because it guarantees that the facilities are clean and sanitary. With this in mind, (Campana et al., 2021) discussed the problem of waste being periodically collected from a hospital facility. The hospital building is complex, with numerous floors, and each room has unique characteristics. The tasks are defined for each place according to the amount of time required for cleaning and considering the size of the place, and each task also has a time window. The objective is to meet the specified service criteria while keeping the overall labor cost to a minimum. Another important application of multi-period service scheduling is technical equipment preventative service and maintenance scheduling. The strategic continuity of operations often hinges on optimizing maintenance planning, which significantly enhances the reliability of industrial installations and distribution networks (López-Santana et al., 2023). In these systems, each service visit incurs a set fee, and the operational cost increases directly proportional to the time intervals between visits for these routine tasks. The objective is to establish a maintenance timetable that minimizes the overall expenses (Raza & Hameed, 2022). In a study presented by (Jafar-Zanjani et al., 2022), service recipients (fuel stations) are geographically dispersed in different points and areas. To provide equipment repair services at these stations, there are teams consisting of specialists with different skills, and the price of providing services can also vary. In this problem, each customer (the center requesting the service) needs one or more specific services in different periods, while some of them may also request joint services. The objective is minimizing the total maintenance cost and maximizing network ability. Furthermore, multi-period service scheduling problems can be related to some periodic Vehicle Routing Problems (VRP) (Keskin et al., 2023; J. Zhang et al., 2024). Over a multi-period, planning horizon, the periodic VRP aims to reduce total transportation costs by determining visit schedules and routes (Ahmadi Basir et al., 2024). A related work was conducted by (Rodríguez-Martín & Yaman, 2022), where a mixed-integer linear programming formulation for the Periodic VRP that considers driver consistency was presented. Every customer in this problem has a unique set of potential visit schedules, and the exact vehicle must visit them every time. Maintaining driver consistency means sending the same driver to each customer's location. The goal is to enhance the service by leveraging drivers' familiarity with customers, routes, and traffic situations. Similar research addressed the scheduling of multi-period service problems such as (Naser Sadrabadi et al., 2020) and (Naderi et al., 2023). The former has introduced a novel periodic problem in the context of service scheduling. In this problem, university instructors allocate a portion of their time each week to guide students. This guidance is typically dispensed through periodic sessions over a specific period, such as one month or half of an academic year. Each student requires a specific duration to receive the service. This matter aims to distribute the requests evenly throughout the program. The latter has examined an integrated approach to home care scheduling, routing, assignment, and staffing throughout multiple periods. In this context, each patient necessitates one or more visits from caregivers possessing a particular skill level on a weekly multi-period planning horizon. The objective is to develop a weekly schedule that satisfies pertinent operational considerations and ascertains the most efficient staffing of caregivers through the minimization of fixed and overtime expenses.

2.2 Customer Preferences

Improving the adaptability of services requires careful consideration of customer preferences and satisfaction. Generally speaking, customer satisfaction is a crucial metric for assessing the quality of services (Park, 2023). In this regard, customers' preferences in scheduling decisions have been the subject of various studies. For example, various research has examined the continuity of care, which is crucial from the patient's point of view in the home healthcare scheduling problem (Makboul et al., 2024). In addition to the time window violation, preferred time slot, uncovered visits, and waiting expenses, other client preferences have also been considered in the service scheduling literature (Cinar et al., 2021; Feldman et al., 2014; Wen & Chen, 2023). A single-objective mathematical model was developed by (T. Zhang et al., 2023) to reduce patient waiting time in consideration of consumer preferences. They also took into account shared preferences between caregivers and patients. Another study is that of (Tunçalp & Örmeci, 2024), which focuses on developing a model for appointment scheduling that considers patient preferences and revenue to determine which days to provide each patient type. (Jiang et al., 2020) examined the scheduling of liner shipping problems by taking into account the time preferences of significant customers for container lines when creating a practical shipping timetable. The study demonstrated that the time preferences of this customer impacted the overall cost and the arrival time of the ship. Similarly, the study of (Li et al., 2021) proposed a mixed-integer nonlinear and convex programming model to explore patients' preferences for skill and doctor-patient familiarity. The studied literature clarifies that multi-period service scheduling has numerous practical applications, and extensive literature is available on this topic. Developing exact, heuristic, and meta-heuristic solutions have all been the subject of extensive studies. Additionally, the fact that service systems involve multiple stakeholders has led to many scheduling models in the literature that consider stakeholder preferences. However, to the best of our knowledge, the literature has yet to examine all the various types of customers' visit preferences simultaneously. In many real-world problems, customers have different preferences for visit times during the planning period. Such requirements led us to develop a novel mathematical model that not only considers these specific customers' preferences on visit schedules but also can downgrade costs by minimizing the employing of resources in service scheduling problems, a unique approach not yet explored in the literature.

3. Problem Statement and Model Formulation

This paper introduces a novel mathematical model that addresses the multi-period service scheduling problem, considering the varying visit preferences of customers. The model operates within a finite planning horizon, divided into a fixed set of set of uniformly intervals. It caters to a group of customers who periodically require a specific type of service, with their visit periods determined by their preferences and regularity of visits. The characteristic of having consistent customer visits during a scheduling period, a common feature in many multi-period scheduling problems, is also considered. Based on (Bender et al., 2016)'s findings, there are four patterns of visit frequencies described in the literature, as presented in Table 1. Here, we take into account a single representative customer, a four- week planning horizon, and a weekly cycle of five days. The filled circles indicate the customer's visiting days.

Table 1. Different types of regularity.

Week				1					2					3					4		
Type of Regularity	Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1		●			●								●	●							
2			●		●		●		●		●		●		●		●		●		●
3			●			●							●			●					
4			●					●					●					●			

It is worth noting that the only distinction between visit pattern type 2 and type 4 is based on the number of days between visits. In type 4, it is a multiple of the number of days per week. For example, visits to customers with regularity type 2 occur every other day, whereas type 4 customers are visited once every five days. The model developed in this work represents both types of regularity in a similar manner. Thus, we consider three different types of visit pattern regularity including types 1, 2, and 3. Additionally, in order to fulfill service requests according to customer preferences, a group of operators is available to provide the service either on-site or remotely. The capacity of operators in each time period is fixed. We aim to establish a service schedule that fulfills all service requests based on customers' preferences while minimizing the total number of operators needed for the service. As an example of the practicality and efficacy of the suggested approach, consider the following scenario: Table 1 shows the optimal solution of a multi-period service system with four customers and two operators with a daily service capacity of two customers. The customer calendars are shown as follows: $C_1 = \{1,4,12,13\}, C_2 = \{2,4,6,8,10,12,14,16,18,20\}, C_3 = \{2,5,12,15\}$, and $C_4 = \{2,7,12,17\}$. With each operator capable of handling a maximum of two visits per day, we require one operator for days 1, 4, 5, 6, 7, 8, 10, 13, 14, 15, 16, 17, 18, and 20, and two for days 2 and 12. This leads us to the conclusion that a total of 17 operators will be needed for the entire 20 days.

3.1. Assumptions

1. The actual periods when service requests arise are not predetermined.
2. Any request must be completed within a single period, and no customer is allowed to submit multiple requests within a period.
3. Each customer's visit preference regularity pattern remains constant throughout the time horizon.
4. Each time, a different operator may visit a customer.
5. There are no precedence relationships and all services are of equal priority.
6. The capacities of all operators are equal and remain constant throughout the planning horizon.

3.2. Notations

In this section, all symbols used in the paper are described in Table 2.

Table 2. Summary of the notation for the multi-period service scheduling model.

Indices	
i	The index belongs to the set of customers
j	The index belongs to the set of days
k	The index belongs to the set of operators
Sets	
F	Set of customers type 1
P	Set of customers type 2
S	Set of customers type 3
T	Set of days in the planning horizon
K	Set of operators

Parameters	
$\mathbf{b_{is}}$	Number of visits of customer i type 3 in the planning horizon
$\mathbf{b_{if}}$	Number of visits of customer i type 1 in the planning horizon
$\mathbf{d_i}$	Service intervals of customer i type 2
$\mathbf{N_f}$	Number of customers type 1
$\mathbf{N_s}$	Number of customers type 3
$\mathbf{N_p}$	Number of customers type 2
$\mathbf{R_{is}}$	Week rhythm of customer i type 3
$\mathbf{R_{if}}$	Week rhythm of customer i type 1
$\mathbf{Q}$	The maximal capacity of operators
$\mathbf{C}$	Number of operators
$\mathbf{m}$	Number of days per week
$\mathbf{W_j}$	Week of day j
Decision Variables	
$\mathbf{X_i^j}$	1 if customers $i \in P$ is visited in day j, otherwise 0
$\mathbf{Y_{ik}^j}$	1 If customer $i \in P$ is visited by operator k in day j
$\mathbf{L_k^j}$	1 if operator k is used in day j, otherwise 0

3.3. Mathematical Model

This section explains the equations corresponding to the objective function and the constraints of the multi-period service scheduling problem. The proposed model, formulated through PILP, introduces a key innovation, i.e., the consideration of different patterns of regularity. Our mathematical model demonstrates that considering these regularity types have profound practical implications in service scheduling. Incorporating these patterns into scheduling strategies can significantly enhance service delivery and customer satisfaction.

$$\text{Min } z = \sum_{j \in T} \sum_{k \in K} L_k^j \tag{1}$$

$$s.t.$$

$$\sum_{j=1}^{d_i} X_i^j = 1 \qquad \forall i \in P \tag{2}$$

$$X_i^j = X_i^{j+d_i} \qquad \forall i \in P, j \in \{1, \dots, |T| - d_i\} \tag{3}$$

$$X_i^j = X_i^{j+m*R_{is}} \qquad \forall i \in S, j \in \{1, \dots, |T| - m * R_{is}\} \tag{4}$$

$$X_i^t + X_i^j \leq 1 \qquad \forall i \in S, t \in \{1, \dots (R_{is} - 1) * m\}, j \in \left\{(W_j * m) + 1, \dots, R_{is} * m\right\} \tag{5}$$

$$\sum_{j \in T} X_i^j = b_{is} \qquad \forall i \in S \tag{6}$$

$$\sum_{j=m*t+1}^{m*(t+1)} X_i^j = \sum_{j=m*(R_{if}+t)+1}^{m*(R_{if}+t+1)} X_i^j \qquad \forall i \in F,\ t = \{0, \dots \frac{|T| - m*(R_{if}+1)}{m}\} \tag{7}$$

$$X_i^t + X_i^j \leq 1 \qquad \forall i \in F, t \in \{1, \dots (R_{if} - 1) * m\}, j \in \left\{(W_j * m) + 1, \dots, R_{if} * m\right\} \tag{8}$$

$$\sum_{j \in T} X_i^j = b_{if} \qquad \forall i \in F \tag{9}$$

$$X_i^j = \sum_{k \in K} Y_{ik}^j \qquad \forall i \in P, S, F, j \in T \tag{10}$$

$$\sum_{i \in P,S,F} Y_{ik}^j \leq Q * L_k^j \qquad \forall k \in K, j \in T \tag{11}$$

$$Q * L_k^j \leq \sum_{i \in P,S,F} Y_{i,k-1}^j \qquad \forall k \in K \backslash 1, j \in T \tag{12}$$

$$X_i^j,, Y_{ik}^j, L_k^j \in \{0,1\} \qquad \forall i \in P, S, F, k \in K, t \in T \tag{13}$$

The objective function (1) is to minimize the overall number of service operators. Constraints (2) determine the initial visit for type 2 customers. Constraints (3) enforce the requirement of having consecutive service periods across the planned horizon. Constraints (4) and (5) ensure that the customers of type 3 have been assigned to a day that aligns with their preferred pattern. Constraints (7) and (8) are analogous to constraints (4) and (5) but refer to customers type 1 instead of type 3. The total number of requests visits for customers type 3 and 1 during the planning horizon are imposed by constraints (6) and (9), respectively. A customer's allocation to a specific operator is guaranteed by constraint (10) if the customer is visited on a day. Constraints (11) limit the amounts of customers that each operator may serve in a given period. According to constraints (12), an operator is not required on any given day until all the prior operators are fully occupied. Finally, constraint (13) is the domain constraint that enforces binary variables.

4. Computational Experiments

In this section, the effectiveness of the proposed model is illustrated through its application to a numerical example in small size. The manageable solution space of small problems allows for a detailed examination, confirming all the conditions raised and desired by the decision-maker. This research made use of IBM ILOG CPLEX 22.1.0 to execute the mathematical model, and the problem was solved using the branch and cut (B&C) algorithm. The branch and cut (B&C) approach, which guarantees optimality and has a track record of success in addressing integer programming problems, has been employed in this study (Elf et al., 2001). If there is a set of linear programming (LP) problems with parameters that can only take on integer values, this approach is a well-known combinatorial optimization technique. Table 3. presents the properties of the successfully solved small example, further emphasizing the reliability of the tools used in the study.

Table 3. Properties of the considered small example.

Number of customers	Number of caregivers	Capacity of caregivers	Time period (days)	Days per week
10	5	3	20	5

In this small example, ten customers (three customers type 1, three customers type 2, and four customers type 3) and five operators with a capacity of three allocated visits per day are considered. It is worth mentioning that week rhythms are consistent and regarded as two for all customers in types 1 and 3. Tables 4 to 6 list the attributes for each group.

Table 4. Properties of customers type 1 in the small example.

Customer number	Number of visits in the planning horizon
1	6
2	6
3	8

Table 5. Properties of customers type 2 in the small example.

Customer number	Service interval
1	4
2	5
3	3

Table 6. Properties of customers type 3 in the small example.

Customer number	Number of visits in the planning horizon
1	8
2	6
3	4
4	6

The result of the proposed model is shown in Tables 7 and 8. In Table 8, each circle in every column indicates that the customer is assigned to that period. For example, the calendar for customer number one in types 2 is $C_1 = \{1,5,9,13,17\}$. Since $Q = 3$, we need one operator for each of the all days except days 8 and 9, two operators for day 9. Therefore, a total number of 20 operators in the twenty days is needed.

Table 7. The results for the small example.

Optimal Function Value	Number of Variables	Number of Constraints	Computational Time (Seconds)
20	1300	659	3.74

Table 8. Visual representation of the optimal solution to small example.

Week	Customer Type / Day	2			3				1			# of operators
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	
1	1	●			●						●	1
	2		●							●		1
	3			●						●	●	1
	4				●					●	●	1
	5	●			●						●	1
2	6			●		●		●				1
	7		●					●	●			1
	8											0
	9	●		●		●	●	●	●			2
	10					●	●		●			1
3	11				●					●	●	1
	12		●	●	●							1
	13	●								●	●	1
	14				●					●	●	1
	15			●	●						●	1
4	16					●		●	●			1
	17	●	●					●				1
	18			●					●			1
	19					●	●	●				1
	20					●	●		●			1

4.1. Case study

This section evaluates the suggested model addressing the multi-period home healthcare scheduling problem. This problem, which is a kind of service scheduling problem, involves a group of customers (patients) dispersed across a geographic area who need home healthcare services (medical and paramedical needs) provided by a set of caregivers (operators) over a particular time horizon (Boshrouei Shargh et al., 2024). Healthcare providers must arrange appointments to offer services at patients' homes. The objective is to design a schedule that satisfies all parties involved in terms of cost, patient satisfaction, the delivery of necessary care, and compliance with different preferences and constraints. Figure 2 depicts the visual representation of the home healthcare problem.

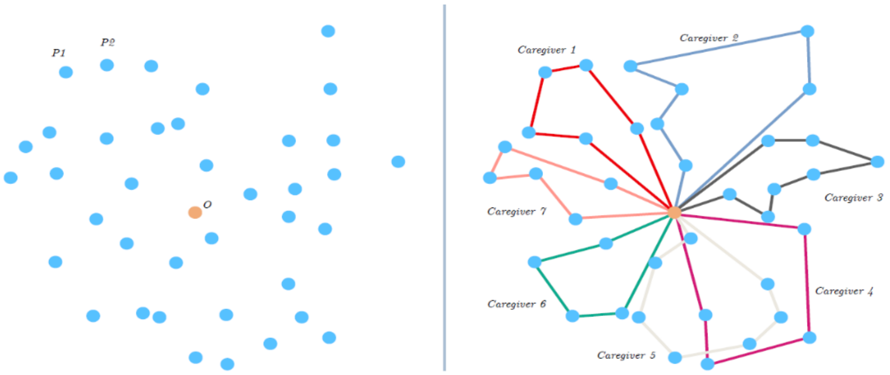

Figure 2. Home healthcare scheduling problem.

The multi-period service scheduling problem for a 28-day planning horizon (four weeks and seven days per week) was solved using the suggested model in a home healthcare organization. The model is solved using IBM ILOG CPLEX 22.1.0 and runs on a computer with an Intel i7-8565U processor,1.99 GHz in CPU, and 8 GB of RAM. Tables 9 to 12 show the characteristics of the case study.

Table 9. Properties of the multi-period service scheduling problem.

Number of customers	Number of caregivers	Capacity of caregivers	Time period (days)	Days per week
30	**8**	**3**	**28**	**7**

Table 10. Properties of customers type 1.

Customer number	Number of visits in the planning horizon
1	6
2	6
3	8
4	4
5	6
6	4
7	8
8	4

Table 11. Properties of customers type 2.

Customer number	Service interval
1	5
2	7
3	4
4	7
5	5
6	4
7	6
8	3
9	10
10	14

Table 12. Properties of customers type 3.

Customer number	Number of visits in the planning horizon
1	6
2	2
3	2
4	8
5	4
6	6
7	8
8	10
9	4
10	4
11	2
12	6

The obtained solution for solving the case study is presented in Tables 13 and 14. Tables 13 demonstrates that all patients have been assigned throughout the planning horizon under the established preference visit pattern. For example, the patient's visit schedule for patient 16, which needs to be scheduled every two weeks on specific days throughout the planning horizon, is $C_{16} = \{1,6,7,15,20,21\}$. In addition, the total number of caregivers needed to provide services is 53, according to the optimal solution obtained in the planning horizon. With respect to day 14 and considering that no caregiver is allowed to see more than three patients per day, it is clear that three caregivers are required for the patients visited on this day. Caregivers' allocations to patients on day 19 are shown in Figure 3 for a more straightforward illustration of the new model's outcomes.

Table 13. The results for the multi-period service scheduling problem.

Optimal Function Value	Number of Variables	Number of Constraints	Computational Time (Seconds)
53	7784	2669	4.29

Table 14. Visual representation of the optimal solution.

Week	Type / Day	2										3												1								# of Caregivers
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	X_{26}	X_{27}	X_{28}	X_{29}	X_{30}	
1	1											●					●	●					●	●					●			2
	2			●	●				●														●									2
	3						●								●										●							1
	4	●				●									●										●		●		●			2
	5							●	●							●		●					●	●								2
	6		●	●											●		●			●					●							2
	7						●					●			●	●	●	●		●				●			●					3
2	8								●				●						●							●		●		●		2
	9	●			●	●																										1
	10			●						●				●					●		●					●		●		●	●	3
	11						●	●	●		●								●											●		2
	12																															0
	13		●										●						●			●				●		●				2
	14	●		●		●			●										●		●					●				●	●	3
3	15						●					●					●	●					●		●							2
	16				●							●						●					●	●	●							2
	17							●	●						●																	1
	18			●											●												●					1
	19	●				●	●									●		●					●	●			●		●			3
	20		●						●	●					●		●			●				●	●				●			3
	21											●			●	●	●	●		●												2
4	22			●				●											●							●		●		●		2
	23				●		●		●																			●		●		2
	24	●				●								●					●		●					●						2
	25										●								●											●		1
	26			●					●																						●	1
	27		●				●												●			●				●		●		●	●	3
	28																		●		●					●						1

Table 15. Visual representation of the optimal solution considering three distinct models.

Week	Type / Day	2&4										3												1								# Of Caregivers
		X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{18}	X_{19}	X_{20}	X_{21}	X_{22}	X_{23}	X_{24}	X_{25}	X_{26}	X_{27}	X_{28}	X_{29}	X_{30}	
1	1			●			●				●						●	●	●													2
	2											●		●					●													1
	3				●				●							●			●				●									2
	4														●		●		●	●												2
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	7														●		●	●														1
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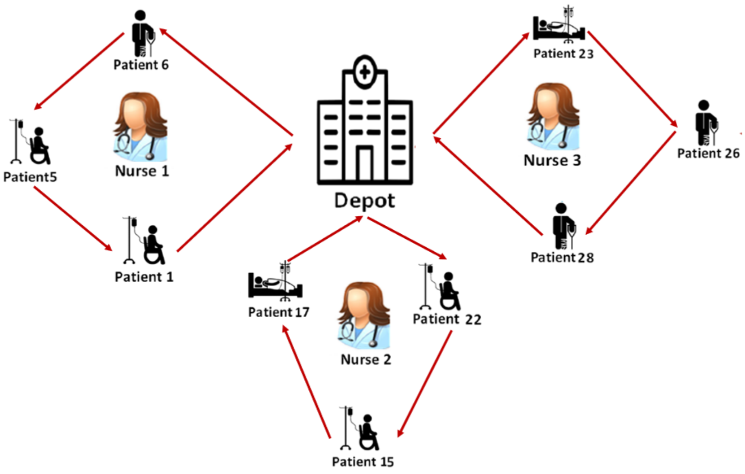

Figure 3. Optimal solution applying the suggested model on day 19.

Now, in order to assess and confirm the effectiveness and applicability of the proposed model, we solve it in three distinct modes. We solve the model individually for each type of customer and then determine the number of assigned caregivers per day and over the entire planning horizon. The results, shown in Table 15, indicate that a total of 56 caregivers are needed throughout the planning horizon, slightly higher than the 53 caregivers required in the model that considered all patient types. Importantly, the proposed model not only meets patients' preferences but also significantly reduces system costs by keeping the number of caregivers required to a minimum across the planning horizon.

4.2. Sensitivity Analysis

In this section, we investigate the problem's behavior across various settings and analyze the impact of significant parameter changes on the case study results. To ensure a systematic and accurate comparison, we ran the model multiple times, modifying a parameter each time. This approach allows us to compare the findings in a systematic and accurate manner. Table 16 presents the findings of this analysis, with the results of the case study discussed in the previous section displayed in the first row. Furthermore, the variations in the parameters, specifically the number of patients in each type and the caregiver's capacities, are depicted in a visual format in Figures 4 to 7. These visual representations provide a clear understanding of the model's effectiveness and its response to different scenarios. We examined the outcomes of the sensitivity analyses by considering six scenarios in each analysis. We observed that the optimal solution increases proportionally to the number of patients across different dimensions, indicating the need for additional caregivers to cater to patient needs. This trend becomes more pronounced as the patient population grows. The findings also clarify that there is no necessarily direct correlation between the number of patients and the calculation time. On the other hand, it is evident that an increase in caregivers' capacities leads to a higher number of daily patient visits. As depicted in Figure 4, the overall number of caregivers will decrease over the planning horizon, reflecting the reduced demand for caregivers to meet the patient's needs.

Table 16. The results for the multi-period service scheduling problem.

Row	Number of customers			Number of caregivers	Capacity of caregivers	Planning horizon (Days)	Wek rhythm	Computational Time (Seconds)
	Type 2	Type 3	Type 1					
1	10	12	8	8	3	28	2	14.73
2	20	12	8	8	3	28	2	24.79
3	10	24	8	8	3	28	2	35.38
4	10	12	16	8	3	28	2	16.18
5	10	12	8	16	3	28	2	30.25
6	10	12	8	8	6	28	2	21.19
7	10	12	8	8	3	56	2	2255.47
8	10	12	8	8	3	28	3	11.45

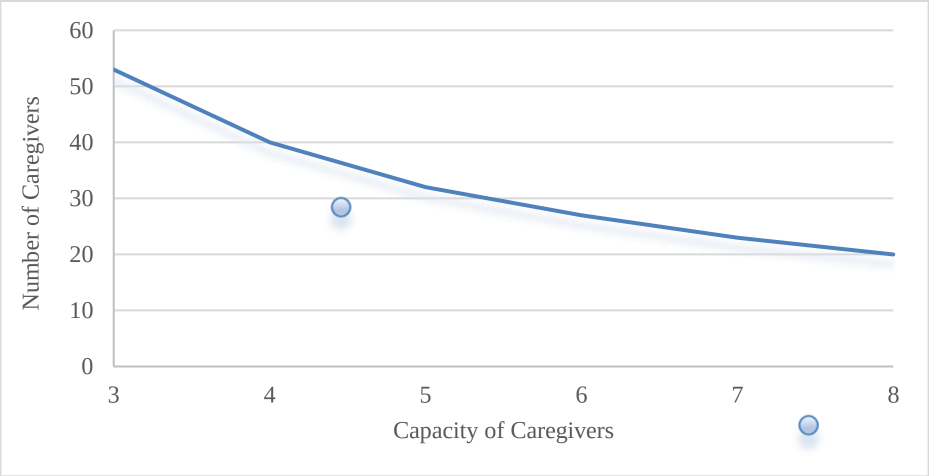

Figure 4. Sensitivity analysis of the total number of caregivers according to the capacity of caregivers.

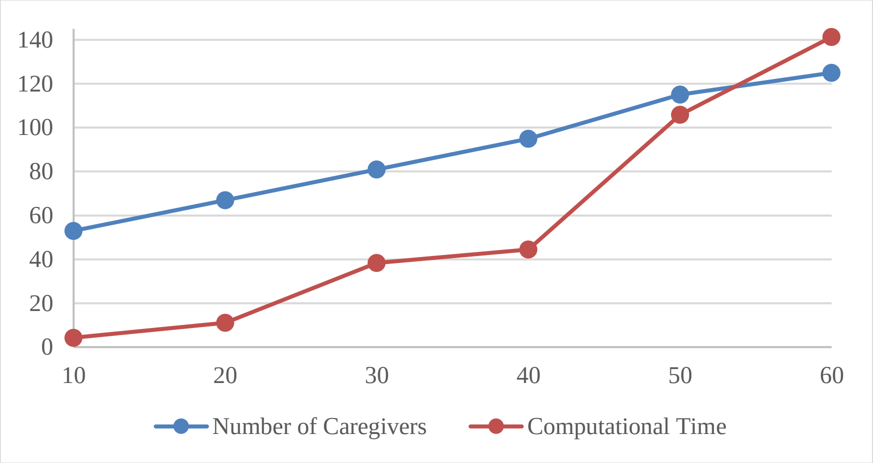

Figure 5. Comparison of results of the large-scale examples, according patients type 2.

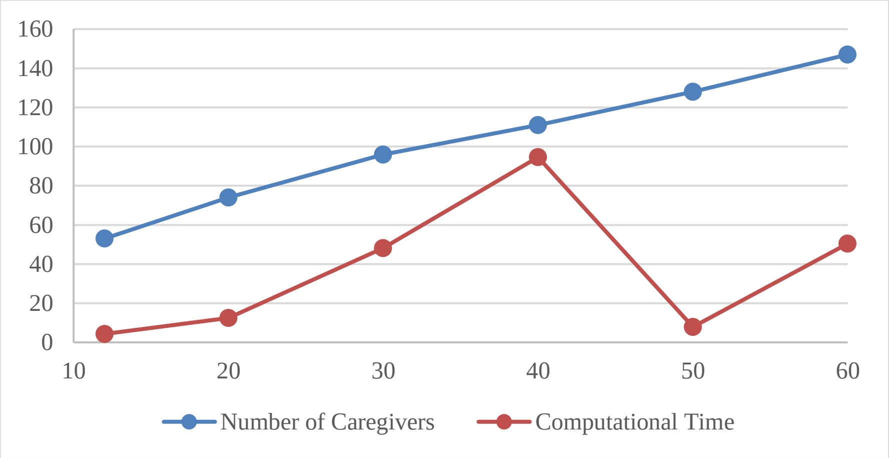

Figure 6. Comparison of results of the large-scale examples, according patients type 3.

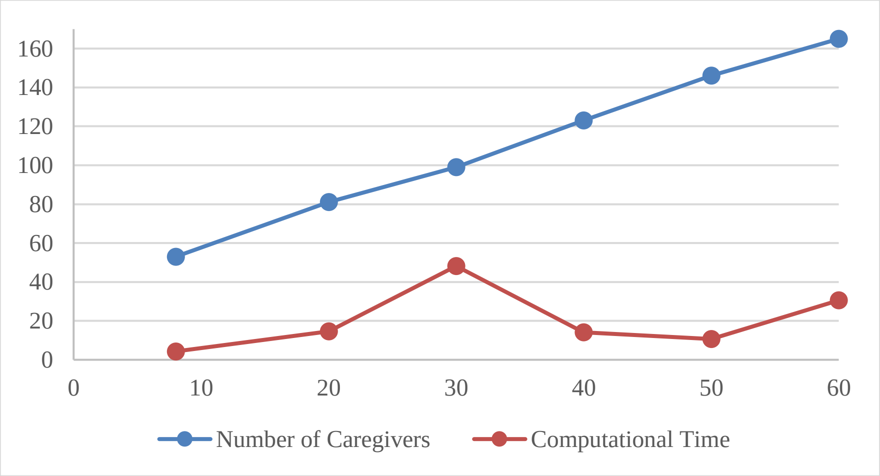

Figure 7. Comparison of results of the large-scale examples, according patients type 1.

5. Managerial Insights

Our findings have yielded several significant insights for managers, which are outlined here. These findings are not just interesting, but they hold significant implications for service industry managers, decision-makers, and researchers. Optimal allocation of limited resources is always considered one of the essential and primary challenges in organizations, especially service industries. Our study challenges the common assumption in service scheduling models, highlighting the practical significance of individual customer preferences in shaping visit patterns. We have identified three distinct types of visit patterns, each reflecting a unique customer preference, which can be leveraged for more effective service planning. In addition, all service organizations have operators to provide services. Aside from mitigating costs, which has been the focus of numerous studies in the literature, another problem with such organizations is that operational level coordination and decision-making will get more complex as the number of operators increases. In light of this, the current study aims to minimize the total number of operators required during the planning horizon. Decision-makers can utilize this model to streamline their processes for handling complicated decisions and effectively manage the capacities of their employees and services. Home healthcare organizations are suggested to plan their human resources according to the demand and patients' preferences about their visit patterns through the planning horizon. Evidently, the more caregivers there are, the more system costs will increase. In other words, obtaining the optimal number of caregivers depends on their capacities and the demand for patients in the system. Staffing up with full-time caregivers rather than dealing with many part-time ones will result in financial savings since, as caregiving capacity increases, the overall number of caregivers reduces throughout the planning horizon. This is in addition to the fact that having a core team of full-time staff can lead to more efficient scheduling and simplify the scheduling process compared to managing a larger pool of part-time staff. Moreover, our research underscores the value of shorter planning horizons. The case study's sensitivity analysis revealed that the computing time significantly increases as the planning horizon extends. Therefore, we recommend healthcare organizations optimize schedules for shorter periods, such as daily or weekly intervals. With its shorter time horizons and fewer variables, this approach offers many advantages. It enhances flexibility, improves responsiveness, boosts planning accuracy, and fosters agility, which is crucial for effective resource management.

6. Conclusion and Future Remarks

Planning and strategically coordinating resources and procedures to meet customer demand effectively is essential in every service industry, such as healthcare and transportation. Service operations management has recently attracted much academic interest since the service industry accounts for the largest share of the world's GDP in terms of value added. Therefore, efforts to understand and describe the mathematical foundation of services have been growing in this area. In such systems, the success of an organization depends on its ability to allocate and schedule its resources. Determining the times when these services must occur is an essential part of service scheduling. In particular, various situations exist in service systems where resources are utilized to meet specific recurring demand requirements over a planning horizon. In this study, we studied multi-period service scheduling problems. This study presented a mathematical model to consider distinct visit patterns, which have practical applications in many service systems. To demonstrate the applicability of the proposed model, a small numerical example and a real case study in a home healthcare organization were run to demonstrate its validity. The interpretation of the results further demonstrated the significance of the proposed model. Moreover, a sensitivity analysis was performed on all parameters to examine how the problem's crucial parameters were affected. Finally, the decision-makers were given some managerial advice on efficiently managing their limited resources. This work opens up a number of opportunities for further research in the field. The first direction can refer to situations where more than one service organization provides the services. When entities in a collaborative system share resources, this problem can occur. Moreover, future studies can consider the concept of varying capacities. This is especially true for operators with varying degrees of competence. As an additional possible direction for future studies, it is recommended that uncertainty be incorporated into the study. Another possible approach to solving the proposed model is to use enhanced exact approaches, like the Benders Relaxation method. In addition, applying heuristic and metaheuristic approaches can be beneficial when exact methods are not applicable to large-scale problems. When it comes to considering various stakeholders, numerous viewpoints could be employed to examine the service scheduling problem. Consequently, it is possible to address many competing goals using multi-objective optimization techniques.

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