

Outpatient Chemotherapy Process with Home-Based and Mobile Services: A Decision Framework and Operation Optimization

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Abstract

Delivering chemotherapy at home or in mobile chemotherapy units has become increasingly popular due to its convenience and patient-centered approach. However, the high demand, complexity, and stochasticity of the Outpatient Chemotherapy Process (OCP) can lead to inefficiencies in implementing these services. To address this gap in the literature, this study presents a decision support framework and operational model for optimizing the OCP with the inclusion of home-based and mobile chemotherapy services. Data-driven research and relevant literature have been integrated to formulate the decision-making process in the proposed decision support framework. A mathematical model is developed to determine the patient and nurse assignments to outpatient department, home, or mobile chemotherapy services, as well as appointment scheduling. A discrete event simulation model is employed to solve the proposed model and determine the performance measures. The optimization experiment included various demand scenarios, and the results showed the value of implementing home-based and mobile chemotherapy services on patient waiting time and staff overtime under all the considered scenarios compared to a baseline. Finally, implementation and modeling strategies have been proposed for scholars and decision-makers to build on this work and benefit from its findings.

Keywords

Home-based chemotherapy, mobile chemotherapy unit, outpatient chemotherapy, optimization, and simulation.

1. Introduction

Cancer is a major global public health concern, and its incidence is expected to rise by 50% from 2020 to 2040 (Bray et al., 2018). Cancer treatment options include surgery, radiotherapy, chemotherapy, or a combination of these methods. However, chemotherapy faces unique operational challenges such as long waiting times and resource overtime (Hadid et al., 2022a). Despite these challenges, more than half of global cancer patients required chemotherapy in 2018 (Bray et al., 2018), and Wilson et al. (2019) predict a looming health crisis due to unmet chemotherapy demand over the next two decades.

Compared to the management of patient operations in hospitals, chemotherapy has specific characteristics, including a duration of about one up to eight hours and a requirement for pharmacy preparation and coordination between

different departments (Lamé et al., 2020). Therefore, the optimization of chemotherapy operations planning poses a challenge due to the partial presence of medical human resources and the need for synchronization and coordination, leading to long patient waiting times and resources overtime. Thus, it is clear that chemotherapy operations need new improvement methodologies (Hadid et al., 2021).

Unlike surgery and radiotherapy, chemotherapy can be administered outside of the hospital setting (Fhoula et al., 2022). To address the challenges posed by the complexity of chemotherapy operations and corresponding time constraints, the concept of home-based chemotherapy (HChemo) and Mobile Chemotherapy Unit (MCU), also called chemo buses, has emerged. These alternatives aim to prevent long patient waiting times, reduce hospital costs and capacity saturation, and efficiently use available resources by enabling patients to receive treatment at home or in their communities (Mitchell, 2013).

Decisions related to the implementation of HChemo and MCUs can be divided into two levels: strategic and operational. Strategic decisions include determining whether to apply HChemo only, MCU only, or both, as well as determining the number of MCUs, nurses, vehicles, and pharmacists required. Operational decisions involve determining which patients should be assigned to Outpatient Chemotherapy Center (OCC), HChemo, or MCU, the number of nurses assigned to each option, and the appointment start times. These decisions should be made to achieve various objectives, such as reducing patient waiting time, minimizing resources overtime, and increasing capacity.

1.1 Objectives

Building upon the aforementioned challenges in the chemotherapy Operations Management (OM) and the emerging concept of HChemo and MCU, this paper takes a closer look at the research on the implementation of HChemo and MCU over the past decades. With a solid grounding in this context, the paper uses data-driven research and OM techniques to offer valuable strategies and insights for the successful implementation of HChemo and MCU.

2. Literature Review

Several countries, such as UK, Australia, Canada, and France have implemented successful home or MCU chemotherapy programs (Evans et al., 2016; Fhoula et al., 2022; Margier et al., 2021). HChemo has several benefits including reducing OCC congestion, providing care in the comfort of the patient's home, promoting healing, and providing more safety from infections (Touati et al., 2016; Zhang et al., 2010). MCU offers a flexible way to receive treatment without long-distance travel, reducing travel time and balancing treatment with other obligations (Iredale et al., 2011). MCUs offer an innovative and patient-centric approach, benefiting all patients while reducing the burden on healthcare providers.

The typical logistic services in the HChemo and MCU involve delivering treatments (drug administration) to patients, picking-up biological samples from patients at home or in the MCU, collecting medical waste from the homes of patients or the MCU, and bringing them back to dispose of, etc. To be an efficient and cost-effective health care alternative, HChemo and MCU services need to be planned and delivered while using the minimum of resources without any disturbance to patient care quality. This requires answering several questions, including:

- What stages of the Outpatient Chemotherapy Process (OCP) can be shifted to the HChemo or MCU?
- Which patients can be eligible for HChemo and MCU?
- What implications are there for the healing of patients?
- What resources are needed to achieve the selected HChemo and MCU?
- How to efficiently manage the HChemo and MCU operations?
- What implications are there on OCC's systems?

The literature attempting to answer these questions is divided into two categories. The first group focuses on evaluating aspects such as patient preference, satisfaction, outcomes, economic impact, compliance, and safety, with two key documents leading this research by Close et al. (1995) and Borrás et al. (2001). For MCU, scholars mainly address the patient experience and perspectives (Iredale et al., 2011; Mitchell, 2013).

The second group of literature, with fewer publications, addresses the performance improvement of HChemo service, but there is a clear absence in addressing the operational challenges of MCU. Studies by Zhang et al. (2010a) and Zhang et al. (2010b) using DES to model the process of HChemo have provided solutions for achieving a defined service level with the minimum staff size and minimizing coordination time between resources. Sahin & Matta (2015) described the specificities of HChemo operations and reviewed relevant models while providing an activities-actors matrix for understanding the process of developing realistic models. Nevertheless, in the pioneering work of Chahed et al. (2009), the HChemo process was comprehensively described, and six optimization models were presented based on the number of routes and patient availability time window. A mathematical formulation was provided for one of these models, which to date is the only one in peer-reviewed literature.

2.1 Research gap and decision support framework

An extended model based on Chahed's et al. (2009) work is necessary to accurately model the operational problem of HChemo and MCUs in OCCs. Incorporating process descriptions from Sahin & Matta (2015) and specificities of chemotherapy OM from Hadid et al. (2021) and Hadid et al. (2022b) can improve the model. It's important to note that studying HChemo and MCUs as separate processes from the processes of outpatient department of the OCCs is not practical or representative of reality. An integrated delivery model that considers OCC, HChemo, and MCU as complementary components is needed. The problem involves optimizing the operations of outpatient department, HChemo, and MCU, while considering patient eligibility and preferences, drug stability, and the need for in-outpatient department stages. The following is a high-level description of the proposed decision support framework:

- **Multi-Objective Function:** Minimize patient waiting time, staff overtime, and transportation costs while maximizing fairness between staff, resource utilization, and the number of served patients. Patient waiting time for OCC, HChemo, and MCU should be considered since they are served by the same resources. Similarly, staff overtime depends on drug production schedules in the pharmacy that serves patients in outpatient department, homes, and MCUs. Transportation costs are essential in home-based services. Fairness among staff delivering services in outpatient department, HChemo, and MCUs is important to ensure a balanced workload. Finally, resource utilization and the number of served patients should be maximized to make the most of available capacity.
- **Constraints:** The constraints of OCP in outpatient department that are described by Hadid et al. (2022c) should be revised to consider the processes of HChemo and MCUs. Furthermore, the following constraints should be added:
 - The drug administration stage can be performed at home or MCUs for eligible patients only.
 - The service provided at the patient home should start and end within the availability time window of the patients at their homes or communities in the case of MCUs.
 - The drug shipping and administration should be completed before the expiry time of the drug.
 - The nurse can be assigned to patients in either the outpatient department, homes, or an MCU on a given day, but not more than one option of these.
 - Vehicle routing constraints
- **Decisions:**
 - The assignment of an eligible patient to either the outpatient department, HChemo, or an MCU to perform drug administration stage.
 - Planned arrival day and time for patients who are assigned to the outpatient department or MCUs to perform drug administration stage.
 - Planned nurse arrival day and time to the homes of patients who are assigned to HChemo to perform drug administration stage.
 - Location to perform stages other than drug administration for each patient (outpatient department, home, or MCU).
 - Day and time to perform stages other than drug administration each patient.
 - Assignment of nurses to outpatient department, HChemo, or an MCU in a given day.
 - Assignment of pharmacists to outpatient department or an MCU in a given day.
 - The sequence of at-home visits assigned to each nurse.
 - The drugs that are to be taken on each trip (A trip starts from the pharmacy of the OCC in the outpatient department).
 - The locations where an MCU will be stationed on a given day.
 - Duration of an MCU's stay at each location on a given day.

Moreover, readers are referred to Fhoula et al. (2022) for complete knowledge mapping of home cancer care that would help them to understand and build on the existing solutions of problems in the same context.

3. Methodology (12 font)

To achieve our study goal of studying an integrated delivery model that considers operations in the outpatient department, patient homes, and MCUs (Figure 1), we began by extending the OCP model of Hadid et al (2022c), which only considered delivering the service in the OCC. The following subsections will detail the description of the considered problem in this paper, optimization model formulation, simulation model, solving method, and data collection and experimental design that were used to accomplish our objective.

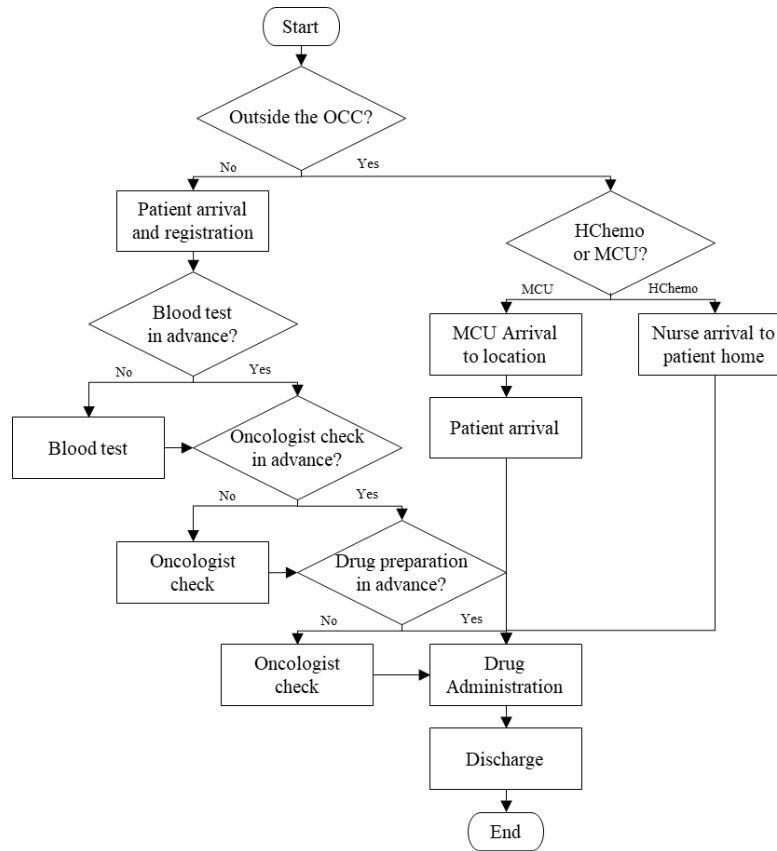


Figure 1. Outpatient Chemotherapy Process (OCP) in outpatient department, homes, and mobile units

3.1 Problem Description

This problem considered in this study is the assignment of patient appointments to either the outpatient department, MCU, or home setting, and scheduling of patient arrival times, taking into consideration the stochastic variables of patient arrivals, service times, and stages to be performed during the appointment. The assignment of nurses to outpatient department, HChemo, and an MCU is also considered, as well as the travel time between patient homes. Only eligible patients are considered for HChemo and MCU, and it is assumed that patients are available in their homes to receive the HChemo service. However, the travel time for nurses from one patient's home to another is a stochastic variable following a specified probability distribution. Prepared drugs are ready to be administered to patients, and they have no expiration duration. Nurses will stay with the patient in their home until the completion of all drug administration processes, including injection, monitoring, removal of drugs, observation, and waste disposal. Patients' arrival time to the MCU is punctual, and the same stochasticity and service times of HChemo apply, without the transportation duration, as the MCU is located in one place for one day. One MCU is considered, and it has a finite number of chairs, and a nurse in the MCU can handle up to a certain number of patients with acuity levels less than or equal to the maximum acuity level that a nurse can handle simultaneously. Prepared drugs are also available in the MCU, and they have no expiration duration.

In order to model patient and drug flow, a queuing network approach is used, with patients and drugs treated as network customers. Subsidiary processes, such as registration, triage, blood tests, drug order activation, and discharge, are modeled as single-class multi-server queues with infinite capacity. Main processes, such as drug preparation and administration, are modeled as multi-class, infinite capacity queues with multiple servers. Service times are based on historical data and follow probability distributions, with drug preparation and administration times varying based on the number of drugs and infusion durations. The system operates under a first-in, first-out (FIFO) policy for patients and drug orders, and all service stations are deemed reliable with no chance of failure or malfunction.

3.2 Optimization Model

As outlined in the problem description, the focus of this study is on operational decisions, assuming that strategic decisions such as implementing HChemo, utilizing MCU, and determining the number of hired nurses have already been made. We extended Hadid's et al. (2022c) operational model to incorporate decision variables and constraints pertaining to HChemo and MCU delivery modes. The following is the extended model.

Indices:

- i Appointment
- z Objective
- n Nurse

Sets:

- \mathcal{J} Appointments
- \mathcal{O} Objectives
- \mathcal{S} Feasible values of x_i and r_i , start time of appointment slots in the time horizon
- \mathcal{N} Nurses

Parameters:

- N_j Number of appointments
- N_o Number of objectives
- LB_i Lower bound of planned patient arrival time x_i of appointment $i \in \mathcal{J}$
- UB_i Upper bound of planned patient arrival time x_i of appointment $i \in \mathcal{J}$

- \mathcal{W}_z Weight of objective $z \in \mathcal{O}$
- N_N Number of nurses
- M Large positive number
- G_i Eligibility for HChemo or MCU, 1 if eligible, 0 otherwise

Decision variables:

- o_i Assignment of appointment $i = 1, 2, \dots, N_j$ to outpatient department, 1 if assigned, 0 otherwise
- h_i Assignment of appointment $i = 1, 2, \dots, N_j$ to HChemo, 1 if assigned, 0 otherwise
- m_i Assignment of appointment $i = 1, 2, \dots, N_j$ to MCU, 1 if assigned, 0 otherwise
- x_i Planned patient arrival time to outpatient department or MCU appointment
- r_i Planned nurse arrival time to HChemo appointment
- v_n Assignment of nurse $n = 1, 2, \dots, N_N$ to outpatient department, 1 if assigned, 0 otherwise
- b_n Assignment of nurse $n = 1, 2, \dots, N_N$ to HChemo, 1 if assigned, 0 otherwise
- y_n Assignment of nurse $n = 1, 2, \dots, N_N$ to MCU, 1 if assigned, 0 otherwise

$$\forall x, o, h, m, r \in \mathbb{R}^{N_j}, \forall v, b, y \in \mathbb{R}^{N_N} \quad \min_x F(x) = \sum_{z=1}^{N_o} \mathcal{W}_z E[f_z(x, o, h, m, r, v, b, y)] \quad \mathcal{W}_z > 0 \quad (1)$$

subject to

$$LB_i \leq x_i \leq UB_i \quad \forall i \in \mathcal{J} \quad (2) \quad x_i \in \mathcal{S} \quad \forall i \in \mathcal{J} \quad (3)$$

$$LB_i \leq r_i \leq UB_i \quad \forall i \in \mathcal{J} \quad (4) \quad r_i \in \mathcal{S} \quad \forall i \in \mathcal{J} \quad (5)$$

$$h_i, m_i \leq G_i \quad \forall i \in \mathcal{J} \quad (6) \quad o_i + h_i + m_i = 1 \quad \forall i \in \mathcal{J} \quad (7)$$

$$v_n + b_n + y_n = 1 \quad \forall n \in \mathcal{N} \quad (8) \quad \sum_{n=1}^{N_N} v_n + b_n + y_n = N_N \quad (9)$$

$$\sum_{n=1}^{N_N} v_n - M \sum_{i=1}^{N_j} o_i \leq 0 \quad (10) \quad \sum_{n=1}^{N_N} b_n - M \sum_{i=1}^{N_j} h_i \leq 0 \quad (11)$$

$$\sum_{n=1}^{N_N} y_n - M \sum_{i=1}^{N_j} m_i \leq 0 \quad (12)$$

For a more detailed explanation of the model formulation, including decision vectors, objective function calculations, and constraints, readers are referred to Hadid et al. (2022c). In this study, we have added several decision vectors, o , h , m , r , v , b , and y , which are used to minimize the objective function. We consider the same objectives as Hadid et al. (2022c), which include patient waiting times and staff overtime while also taking into account the waiting time of patients at home from the planned appointment time to the arrival of the nurse, as well as the waiting time of patients in the MCU for an empty chair to begin the appointment. We also consider nurse overtime in homes and the MCU.

Constraints (4) and (5) define the feasible time slots and planning day for HChemo appointments, while Constraint (6) guarantees that only eligible patients are assigned to HChemo or MCU. Furthermore, Constraints (7) and (8) ensure that each patient and nurse are allocated to only one delivery mode, namely outpatient department, HChemo, or MCU. Finally, Constraint (9) sets a limit on the number of nurses assigned to all delivery modes to ensure that it does not exceed the available number of nurses. Moreover, constraints (10)-(12) are introduced to prevent assigning nurses to outpatient department, HChemo, or MCU when there are no patients assigned to these modes, and vice versa.

3.3 Simulation Model

The outpatient department, HChemo, and MCU integrated delivery process was analyzed and optimized by extending the discrete event simulation model developed and validated by Hadid et al. (2022c). Initially, a process map was added to illustrate all patient flows of HChemo and MCU, and relevant data such as patient eligibility, MCU capacity, and service times were gathered and recorded. This information was then incorporated into the extended simulation model. The stability of the model was checked and the outputs were validated against expected operational outputs to ensure accuracy.

To conduct optimization experiments, decision variables, objective function, and constraints were inputted into the model. Anylogic optimization engine, OptQuest, employs metaheuristics algorithms to determine the solution (AnyLogic, n.d.).

3.4 Case Study and Experimental Design

In this study, a case study approach was used to examine and gain insights from the optimization results of the extended model that considers the outpatient department, HChemo, and MCU processes. The case study was based on a large OCC in the Gulf region, which expressed an interest in implementing HChemo and a MCU. One-day scenarios were utilized to calculate the decision variables, objective functions, and performance measures. This day had 54 appointments, the patient and drug data for this day were obtained from Table S1 published in Hadid et al. (2022c).

To evaluate the impact of the HChemo and MCU processes, we integrated them into the existing outpatient department process model developed by Hadid et al. (2022c). Figure 2 and Figure 3 illustrate the integrated HChemo and MCU processes, respectively. The HChemo process and the number of nurses required were determined by the optimization experiment. Only nurses were considered for HChemo resources. Similarly, the MCU process was integrated. The number of chairs in the MCU unit was kept constant at four, while the number of nurses assigned to the MCU unit was determined through the optimization model. The same number of nurses assigned for regular hours in the outpatient department worked overtime in the MCU process, as they were constrained to this location. The number of chairs in the MCU unit was set to four.

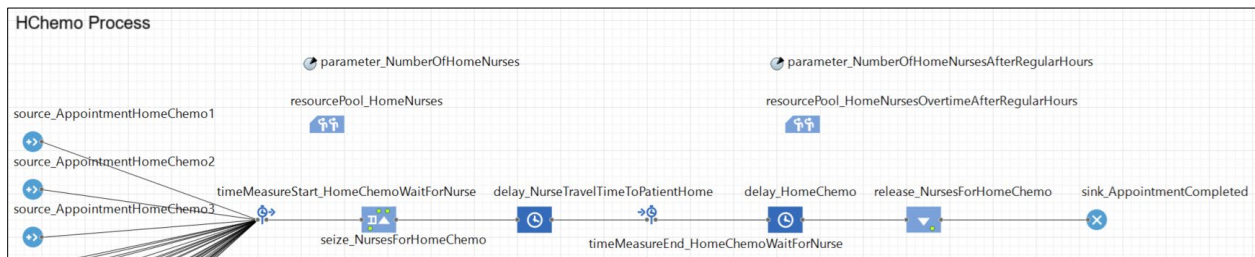


Figure 2. Home-Based Chemotherapy (HChemo) Process

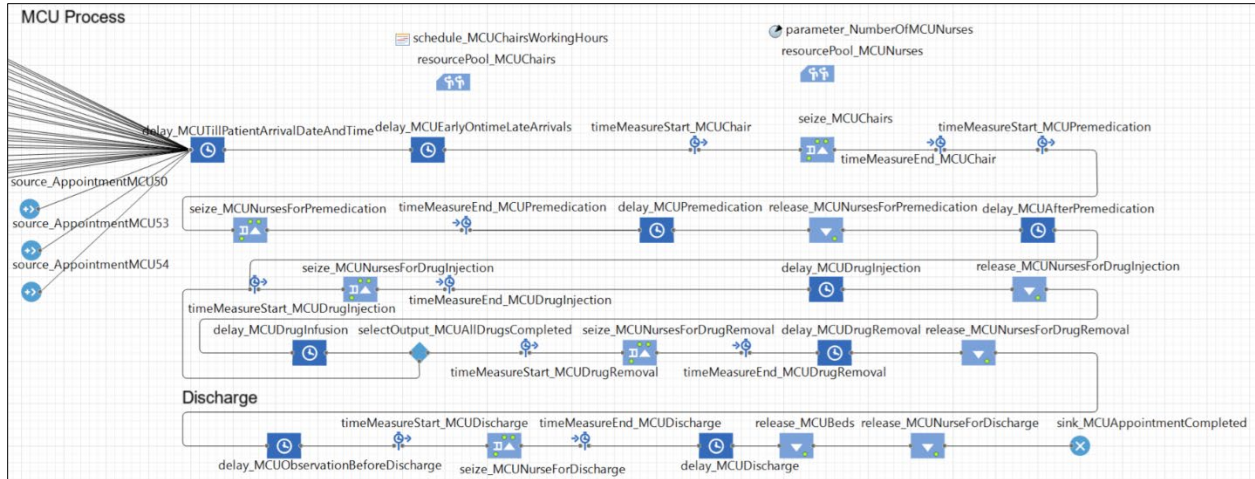


Figure 3. Mobile Chemotherapy Unit (MCU) process

Table 1 presents a summary of the service time and duration distributions, as well as the relevant parameters utilized for the HChemo and MCU processes. The service times for the outpatient department processes were obtained from Hadid et al. (2022c). We used the same service times and number of resources, except for the number of nurses assigned to the regular hours of the outpatient department on the day of the experiment. This was determined by the optimization experiment.

Table 1. Values for Home-Based Chemotherapy (HChemo) and Mobile Chemotherapy Unit (MCU) processes

Parameter	Value	Source
Duration of nurse travel to patient home	triangular(20,60,30) min	Expert opinion
Premedication injection service time	weibull(1.32, 1.2) min	(Hadid et al., 2022c)
Premedication duration	triangular(3, 15, 8) min	(Hadid et al., 2022c)
Drug injection service time	normal(2.13, 2.92) min	Expert opinion & (Yokouchi et al., 2012c)
Drug infusion duration	Patient-specific	(Hadid et al., 2022c)
Drug removal service time	$3.43 \times \text{beta}(0.67, 0.577)$ min	Expert opinion & (Yokouchi et al., 2012)
Final observation duration	exponential(89.70559, 0.94490) min	(Hadid et al., 2022c)
Discharge service time	weibull(1.42, 4.01, 0.90) min	(Hadid et al., 2022c)
Number of patients that can be served by HChemo nurse during drug infusion	1	Expert opinion
Number of patients that can be served by MCU nurse during drug infusion	4	(Hadid et al., 2022c)
Total number of nurses available for outpatient department, HChemo, and MCU	16	Data

The experimental design incorporated four service demand scenarios for two types of patients who were scheduled to receive chemotherapy on the designated day (Table 2). The eligibility criteria for patients to be considered for HChemo and MCU or ineligible to receive chemotherapy outside the outpatient department was complex, requiring a comprehensive study of medical, drug, social, and operational factors. To simplify the analysis, scenario 1 was designed to include patients with inexpensive drugs as eligible for HChemo and MCU, while patients requiring expensive drugs were considered ineligible. This was justifiable since the OCC preferred not to prepare expensive drugs in advance and would, therefore, not send such drugs to HChemo and MCU. Subsequently, scenario 2 included a mix of eligible patients with both inexpensive and expensive drugs, while scenario 3 involved a mix of ineligible

patients with inexpensive and expensive drugs. Furthermore, the baseline setting of the outpatient department without HChemo and MCU was considered.

Table 2. Patient demand scenarios

Scenario	Eligible		Ineligible	
	Number of patients	Type of drugs	Number of patients	Type of drugs
Baseline (HChemo and MCU are not implemented)	0	-	54	31 inexpensive 23 expensive
1	31	All inexpensive	23	All expensive
2	16	All inexpensive	38	23 expensive 15 inexpensive
3	38	31 inexpensive 7 expensive	16	All expensive

The current study employed an optimization experiment for each demand scenario to investigate the impact of patient demand on the scheduling of HChemo, MCU, and outpatient department appointments, as well as nurse assignments to these units and the resulting objective function value. This approach facilitated a comparison of the various scenarios, thus providing valuable insights into the effects of demand variations on the scheduling and staffing decisions for HChemo, MCU, and outpatient department services. The optimization experiment was performed for each demand scenario until the stopping criterion was met, with a maximum of 5,000 iterations. To account for stochastic behavior, a varying number of replications were conducted, stopping when a 95% confidence level and 5% error were reached after a minimum of two replicates for each iteration.

To analyze the objective function and performance measures, the obtained solutions were simulated for 10,000 replications using the Monte Carlo experiment in AnyLogic. This number of replicates was chosen to allow for the analysis of the objective function and performance measures with a Half-Width (HW) within the range of $\pm 1\%$. For each solution, the simulation replicates were executed with random values of the stochastic parameters in each run. The resulting values of the mean, minimum, maximum, standard deviation, and HW of the 95% confidence interval (CI) of the objective function were then reported.

5. Results and Discussion

This section presents the results of the optimization experiments conducted for the scenarios described in the experimental design. The chart in Figure 4 depicts the optimization experiment results for the baseline scenario and scenario 1.

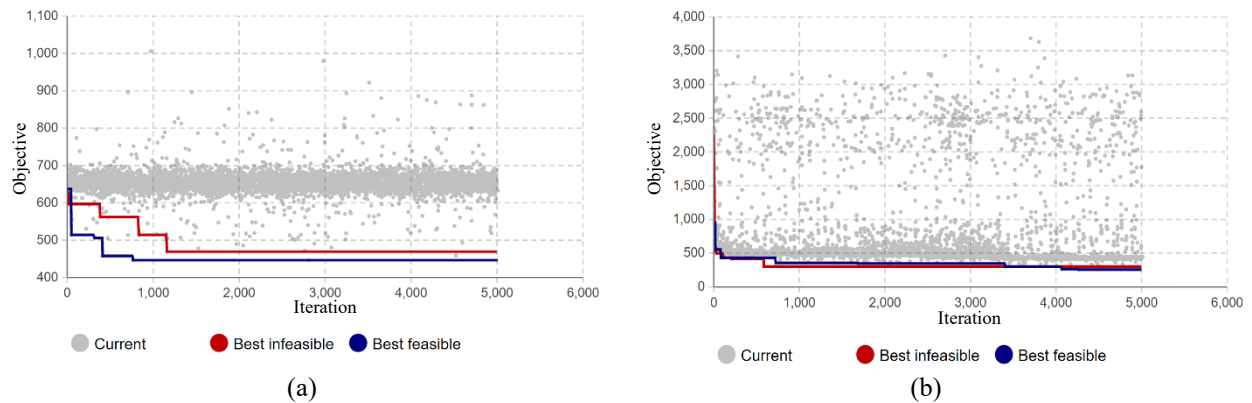


Figure 4. (a) and (b) are the baseline scenario and scenario 1 optimization experiment run results, respectively

It is observed that the objective function value does not show significant improvement after 1,000 iterations. This is

because the optimizer initially focuses on determining the patient and nurse assignments to the outpatient department, HChemo, and MCU, before making slight changes to the appointment start time (i.e., planned patient arrivals to outpatient department and MCU, and planned nurse arrivals to patient homes) to improve the objective function. A similar pattern is observed in the baseline optimization experiment, where the decision variables are limited to the arrival times of patients to the outpatient department. In this case, changes to the patient arrival schedule do not significantly impact the solution after 1,000 iterations. Therefore, alternative decisions need to be taken, such as implementing HChemo and MCU, to improve the objective function.

Figure 5 presents a comparison of the assignment decisions for the four scenarios. It can be observed that HChemo required the highest number of nurses in scenarios 1, 2, and 3, despite not having the majority of patients assigned to it. This can be attributed to the fact that nurses must remain with the patient in their home for the entire appointment and then travel to the next patient. To minimize patient waiting time and nurse overtime in HChemo, a number of nurses almost equal to the number of patients were assigned to this scenario.

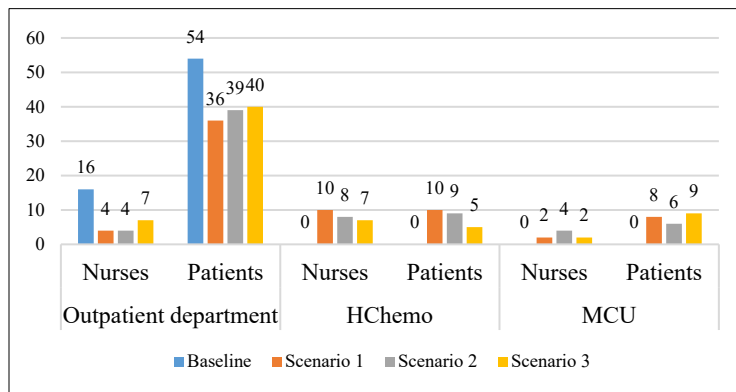


Figure 5. Results of patient and nurse assignments for the four demand scenarios

In contrast, the number of nurses assigned to the outpatient department and MCU was much lower than the number of assigned patients. Nurses in these scenarios can handle several patients simultaneously during drug infusion depending on the acuity level, as they are located in the same place and only require observation and monitoring. In this experiment, up to four patients were handled simultaneously.

Although fewer nurses were assigned to the outpatient department compared to the combined number of nurses assigned to HChemo and MCU, more patients were assigned to the outpatient department than to HChemo and MCU together. This can be explained by the considered patient unpunctuality in arrival times to the outpatient department, as well as the necessary sub-processes, such as registration, drug order activation, and drug preparation. These two factors caused the patient arrivals to outpatient department appointments to be distributed over a longer time span, which reduces the intensity of nurse demand. Therefore, an increase in the number of nurses would not have a significant effect on the average patient waiting time of appointments assigned to the outpatient department.

In scenarios 1 and 3, the number of eligible patients for HChemo and MCU is higher than the ineligible patients. However, not all eligible patients are assigned to HChemo or MCU. For instance, in scenario 1, five eligible patients for HChemo or MCU were assigned to the outpatient department. This indicates that assigning an eligible patient to HChemo and MCU does not always reduce waiting time and overtime. It is the combination of assigned patients, taking into consideration the required service time, eligibility for advanced drug preparations, and other factors, that can improve the objective value.

The results of the assignment decisions between scenarios 1 and 3 suggest that the percentage of eligible and ineligible patients has a minimal effect on the solution when the percentage of eligible patients is higher than the percentage of ineligible patients for HChemo and MCU. However, it should be noted that the degree of improvement in objective value may not be significant, regardless of the difference in the percentages of eligible and ineligible patients. This observation is further supported by the close/similar objective function values obtained for the different solutions of

scenarios 1 and 3, as illustrated in Table 3. Conversely, scenario 2, in which the percentage of eligible patients for HChemo and MCU is lower than that of ineligible patients, resulted in a considerable regression in the objective value. It is worth noting that despite the minimal effect of eligible and ineligible patient percentages, the implementation of HChemo and MCU in scenarios 1, 2, and 3 resulted in a better objective value than the baseline scenario where only chemotherapy is provided in the outpatient department.

Table 3. Objective function values for the considered demand scenarios

Objective	Baseline	Scenario 1	Scenario 2	Scenario 3
μ	410.6	260.1	304.8	298.7
Min	210.8	104.0	131.0	130.6
Max	1,204.3	1,187.3	1,204.4	1,063.7
σ	86.6	76.6	77.7	77.4
95% CI HW	1.7	1.5	1.5	1.5

The difference in patients assignment decisions between scenarios 1 and 3 was minimal, suggesting that the percentage of eligible and ineligible patients for HChemo and MCU had little effect on the solution when the former was higher than the latter. Furthermore, the magnitude of the difference in percentages did not have a significant impact on the improvement of the objective value. This is supported by the comparison shown in Table 3, which indicates that the different solutions of scenarios 1 and 3 are proximate in terms of objective values.

In contrast, in scenario 2, where the percentage of eligible patients was lower than ineligible patients for HChemo and MCU, the objective value regressed considerably. This emphasizes the significance of incorporating a higher percentage of eligible patients for HChemo and MCU during planning patients on days, as it can lead to better outcomes in terms of patient assignment and appointment time scheduling.

Despite the minimal impact of the percentage of eligible and ineligible patients in scenarios 1 and 3, the implementation of HChemo and MCU still resulted in better objective values compared to the baseline scenario, where only chemotherapy was provided in the outpatient department. Therefore, the results support the integration of HChemo and MCU in cancer treatment plans, as they can significantly improve the efficiency and quality of care.

5.1 Proposed Improvements

The findings of the study suggest several improvements that can enhance the performance of the OCP. These proposed improvements are as follows:

- Applying HChemo and MCU concurrently can reduce waiting time and overtime and improve the overall performance of the OCP. HChemo and MCU can complement each other in managing patients with different drug administration durations and acuity levels. However, the decision to assign eligible patients to HChemo and MCU should be made carefully, as several factors can affect this decision. The use of an operational decision support model can assist in determining whether it is better to assign eligible patients to the outpatient department or to HChemo and MCU.
- Considering HChemo or MCU alone without taking into account the operations in the outpatient department might not be practical to enhance the OCP. There are patients who are ineligible for HChemo and MCU and must receive their chemotherapy in the outpatient department. Thus, it is crucial to take into account the overall operations in the OCP while implementing HChemo and MCU.
- A strategic design for resources and the combination of modes is necessary to optimize the number of hired nurses, MCUs, chairs, and the decision of implementing HChemo alone, MCU alone, or HChemo and MCU. This is because these factors are the inputs for the operational decision model. Therefore, an integrated model that can make strategic and operational decisions based on real demand and process data is promising.
- Moreover, regular reviews of the OCP's performance metrics can provide valuable feedback to optimize the system further. It is necessary to evaluate the system's performance, including the waiting time, utilization of resources, and overtime, to identify areas that need improvement and to adjust the system accordingly.

6. Conclusion

This study has contributed to the OM literature by conducting a comprehensive review of the related work on HChemo and MCU and identifying gaps in the literature. The study has developed a comprehensive decision support framework that integrates the HChemo, MCU, and outpatient department processes for optimizing the OCP. Moreover, an operational decision model that combines the HChemo, MCU, and outpatient department processes has been modeled to determine the patient scheduling and nurse assignment decisions. Real data from a large OCC was collected and used to develop and test the model under different demand scenarios. The results confirmed the advantages of implementing HChemo and MCU and proposed strategies for proper implementation and modeling.

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