Discrete Event Simulation for Chemotherapy patient flows

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Abstract

In oncology departments in hospitals, chemotherapy is one of the primary treatments besides radiotherapy and surgery. Depending on the care protocol, patients need to visit the hospital several times to get the drug infusion which could take from 30 minutes to 8 hours. During a hospital appointment, patients go through procedures that may involve various hospital resources. Due to the limited capacity of these resources as well as an increasing number of patients, long waiting times are quite common and cause a negative effect on the quality of care. In this study, we analyze the chemotherapy patient flows an oncology center in Lille (COL), France using Discrete Event Simulation (DES). This simulation study integrates numerous hospital resources as well as different sources of uncertainty to achieve a more practical model. The data for DES are obtained from three sources: electronic health records, expert opinions, and a time study. The simulation results allow us to assess the performance of the current system at COL based on two performance measures: average patient waiting time, and nurse utilization. This simulation work will also be used as a basis to evaluate scheduling algorithms proposed for COL to improve chemotherapy patient flow and better utilize hospital resources.

Keywords

Discrete event simulation, chemotherapy, patient flows, patient waiting time

1. Introduction

The number of patients having cancer problems has increased in recent years resulting in high pressure on oncology departments of hospitals. Chemotherapy, radiotherapy and surgery are some of the main cancer treatments. Chemotherapy requires patients to get anticancer drugs over a period, ranging from several weeks to several months depending on their health status as well as the cancer type they have. Chemotherapy treatments are generally administered by the outpatient service of hospitals in which patients arrive in the hospital and finish their treatments within the same day. Typically, patients go through a sequence of hospital services when treated by chemotherapy: blood test at a laboratory, visit an oncologist, wait for drugs to be prepared by pharmacists, and get their drugs in an infusion area. This sequence involves various hospital resources, including phlebotomists, oncologists, pharmacists, nurses and the related facilities. In addition to the involvement of many resources, there are various sources of uncertainty in the chemotherapy patient flows. Consequently, chemotherapy patients usually experience long waiting times during their treatment day. This fact causes a negative impact on the satisfaction of patients whose health status is relatively weak.

To reduce that waiting time of chemotherapy patients at hospitals, an apparent solution is to reorganize the patient process. A common practice of cancer treatments in France is that blood tests are performed at independent laboratories before the treatment date, and test results will be directly sent to the hospital before the arrival of the patients. Thanks to this practice, patients can reduce the total time spending at a hospital during the treatment date. Also, some hospitals may ask patients to see their oncologists before their treatment date so that on the treatment day their drugs can be well prepared by the pharmacy which is usually a bottleneck of the chemotherapy treatment process. Another solution to this problem may be the drug standardization (or dose banding) by which the dosage for patients is based on the interval of their body information (such as body surface) instead of being specifically calculated for that patient. These standardized treatments can be prepared before the arrival of patients, and hence their waiting time is reduced significantly. With the increasing demand for chemotherapy treatments while the capacity of related resources is limited, the reduction of waiting time for chemotherapy patients is an essential concern for hospitals. This issue becomes more complex when different stakeholders may be involved in the decision making process at hospitals. For instances, an increase in the hospital capacity can reduce patient waiting time but it may impose a financial burden.

In this study, we show that patients' waiting time can be reduced by decisions at operational level, such as appointment scheduling policy. This study is implemented at an oncology center in Lille (COL), France. At this hospital, the chemotherapy treatments are currently administered by the "Hospital de Jour" (HDJ) department with a capacity of 32 treatment chairs and beds (18 beds and 14 chairs). Different groups of cancers are being treated at HDJ: Breast Cancers, Gynecologic Cancers, Urologic Cancers, Upper Aerodigestive tract Cancers (or Voies AéroDigestives Supérieures – VADS), and other general cancers. In 2017, HDJ delivered around 16,000 chemotherapy treatments, corresponding to an increase of 25% compared with 2015. The number of patients getting chemotherapy treatments at HDJ is increasing and leads to long waiting times for patients. Based on daily observations, we find that some patients may need to wait up to 3 hours before getting their treatment in the infusion room. This long waiting time is not only attributed to the time for drug preparation but also partly explained by the insufficiency of nurses or chairs. Therefore, it is necessary to find solutions to improve the current practices at HDJ to reduce the waiting time for patients. Discrete Event Simulation (DES) is proposed to analyze the patient flows at HDJ. The main advantage of simulation compared with other Operations Research tools, such as Queuing Theory, or Mathematical modeling is that it allows us to represent the behavior of a complex system as an ordered sequence of well-defined events; we can then easily integrate various sources of uncertainty as well as various levels of complexity. This tool allows us to evaluate the system more correctly. Based on the simulation model, we can propose and evaluate various policies to improve the current system at HDJ.

The organization of this paper is as follows. A literature review about the patient flow in chemotherapy settings is presented in Section 2. The current setting of HDJ is described in Section 3. Then Section 4 studies the DES for HDJ and analyzes simulation results. In section 5, various policies are proposed and compared with the current setting to see the improvement regarding patients' waiting time.

2. Literature review

Simulation has been used in several studies to model the current system of the oncology department of hospitals. The advantage of using simulation is that it allows users to integrate a wide range of complexity and assumptions to achieve a more practical result. This fact makes simulation a good tool to model patient flows in chemotherapy units. In the literature for chemotherapy patient flows, simulation can be used to support decision making process at 3 levels: strategic, tactical, and operational level. The main purpose is to analyze the impact of different decisions on the performance measures of the system: patient-related metrics, resource utilization metrics, and hospital-related metrics.

In this section, we review studies focusing on the use of DES to improve patient flows at chemotherapy units in hospitals. Studies of DES for analyzing chemotherapy patient flows in literature can be differentiated by four fields: involved processes in the patient flow, performance measures of the system, improved factors, and combined techniques for the system improvement (see Table 1).

Ahmed, ElMekkawy and Bates (2011) model the infusion area to increase the patient throughput without causing a large increase in patient waiting time. A modified patient arrival rate is proposed to avoid the peak demand around the noon time. Authors also test various policies regarding nurse scheduling and nurse capacity increasing, but the results are not as good as the policy related to patient arrival rate. Woodall *et al.* (2013) also use DES to reduce patient waiting time at the infusion area by changing the start time of various nurse shifts as well as the number of available nurses. The optimal solution was found by the combination of simulation and optimization to minimize the expected patient waiting time at the infusion area.

Due to the interdependence of different processes in the patient flows of chemotherapy treatments, to estimate patient waiting time more correctly, various studies integrate upstream processes into the simulation model. Huggins, Claudio, and Waliullah (2014) propose a DES model that takes into account the activity of the pharmacy in addition to the infusion process. This study uses a mathematical model to determine the arrival time of patients so that the chair utilization is maximized. The proposed approach can increase in average 18% the number of patients and keeps the average patient time in the system unchanged.

Liang *et al.* (2015) use DES to simulate chemotherapy patient flow that involves various processes, including blood testing, consultation, and infusion process. The research considers different patient types with different routings in the hospital. To reduce patient waiting time as well as total time in the system, this study uses a patient arrival probability for different patient types at each time interval. This probability matrix is generated by optimizing a mathematical model in which the use of treatment chairs and consultation rooms is balanced throughout a day. The robustness of this scheduling method is confirmed by the use of DES in various scenarios.

As long as upstream processes are considered inpatient flows, waiting time for drug preparation largely contributes to the total patient waiting time. To reduce patient waiting time to get treatment drugs, including the waiting time for pharmacists and the preparation time, Masselink *et al.* (2012) propose a policy for drug preparation so that some drugs can be prepared before the appointment time of patients. This policy also causes a cost for the hospital due to wasted drugs. To evaluate the impact of different policies, authors employ both DES and Markov chain to estimate patient waiting time for drug preparation and the cost of wasted drugs. That study shows that the waiting time for drug preparation can be significantly reduced (from 45 minutes to 23 minutes) if 80% of drugs are prepared in advance.

It can be seen that most of DES papers related to chemotherapy focus on the patient waiting time because this measure is important. To improve the performance of the system, a common approach is to deal with patient arrival process by modifying the arrival rate or solving a patient scheduling problem. Although the drug preparation at the hospital pharmacy causes long waiting time, few papers analyze the impact of this process on the total waiting time. In this study, in addition to the modification of patient arrival rates, we also take into account the impact of different policies implemented at the pharmacy on the patient waiting time.

Table 1. Related simulation studies in chemotherapy patient flow

Study	Involved processes	Performance measures	Improved factors	Combined techniques
Ahmed, ElMekkawy and Bates (2011)	4	1 - 2	1	3
Huggins, Claudio and Perez (2014)	3 - 4	3 - 4	1	1
Liang *et al.* (2015)	1 - 2 - 3 - 4	1 - 3	1	1
Masselink *et al.* (2012)	3	1 - 5	4	2
Woodall *et al.* (2013)	4	1	2 - 3	1
Yokouchi *et al.* (2012)	2 - 3 - 4	1 - 3 - 4	1 - 3	3
Proposed model	2 - 3 - 4	1 - 4	1 - 4	3

Involved Processes: 1. Blood test; 2. Consultation; 3. Drug preparation; 4. Infusion
Performance measures: 1. Patient waiting time; 2. Throughput; 3. Total time in system 4. Resources utilization; 5. Cost
Improved factor: 1. Patient arrival; 2. Nurse scheduling; 3. Nurse capacity; 4. Drug preparation
Combined Techniques: 1. Optimization; 2. Markov chain; 3. Heuristics

3. Current settings at the COL

3.1. Introduction

COL is a medical center that provides different kinds of treatments for cancer patients: surgery, radiotherapy, chemotherapy, and other cancer consultations. In general, when the cancer type of the patient is identified, a multidisciplinary meeting (RCP- Réunion de Concertation Pluridisciplinaire), which includes oncologists, pharmacists, surgeons, to determine a personalized treatment plan for the patient (PPS – Parcours Personnalisé de Soins). This plan takes into account various patient factors: the cancer type and its evolution stage, the patient age, the patient health status as well as their preferences.

The chemotherapy treatments are usually combined with surgery to get a better result for the cancer treatment. Chemotherapy can be proposed before the surgery (Neoadjuvant chemotherapy) or after the surgery (Adjuvant chemotherapy). A chemotherapy treatment plan for patients is composed of a set of treatments defined in a protocol. This protocol describes the rhythms of treatments (or the date patients get treatment), the drugs as well as its dosage used for each treatment. Chemotherapy is usually given in a number of cycles, and each cycle includes treatment dates and recovery dates. As a result, the total length of a protocol may last from several weeks to several months. Before starting the chemotherapy, patients will have an operation to place small equipment (PAC – Port à Cath) so that intravenous drugs are delivered easier.

3.2. Chemotherapy patient flows

At this hospital, the chemotherapy treatment is administered by the outpatient service (or Hospital de Jour – HDJ) which opens from 7h30 to 19h30. Patients arrive HDJ with an appointment communicated by nurses at the end of the previous treatment. Before the treatment date, patients go to a laboratory to do a blood test to make sure that they are able to get the chemotherapy drugs in the next day. The blood test result is directly sent to COL. If the blood test of patients is not fit, the patient is informed by HDJ, and their treatment is delayed to another date. In case the health status of patients is acceptable, patients arrive HDJ on the treatment date to get their drugs.

On the treatment date, patients firstly complete the check-in process at the reception desk of HDJ. Their identity will be checked and printed on a bracelet that patients must keep during their stay at HDJ. Depending on the rhythm described in their protocol, patients need to see an oncologist before getting the drugs or not. After the consultation stage, the oncologist prescribes a prescription and transfer it to the pharmacy to prepare the treatment drugs for patients. The patients then are invited to the waiting room of the infusion area and wait to get the infusion while pharmacists prepare their drugs. If patients do not have a consultation appointment, they go directly to the waiting area after the check-in process. Figure 1 presents a general framework of steps involved in the chemotherapy treatment at COL.

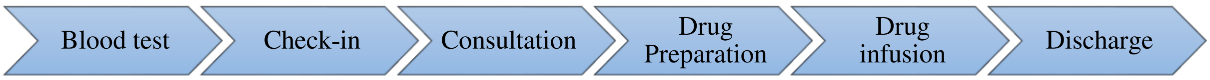

Figure 1. General framework of the chemotherapy treatment

The infusion process can be further divided into three sub-processes. In the first stage called pre-infusion process, nurses collect and prepare drugs provided by pharmacists for patients. This process can last for 10-15 minutes depending on the number of drugs for each patient. When all drugs are available, the nurse will invite a patient to stay in a room or a chair to get his/her treatment. Then, the nurse will check the information of patients, do a basic test (blood pressure, body temperature), clean the PAC, and conduct a simple questionnaire. In the second stage, patients get their drugs and wait until their treatment finishes. After the infusion is finished, in the post-infusion process, nurses will collect equipment, provide information for the next treatment date, and enter patient information into the information system.

3.3. Drug preparation policies

The treatment drugs for chemotherapy patients at COL are prepared by the pharmacy of the hospital. The common practice in various oncology hospitals is that treatment drugs will be prepared after a consultation with an oncologist. The advantage of this procedure is to make sure that patients are in a good health status before getting the chemotherapy treatments and the treatment is specific to that patient. However, this process causes long waiting time for patients due to the time needed for the drug preparation as well as the limited capacity of the pharmacy. To remedy this situation, some hospitals adopt a policy so that some treatment drugs for patients can be prepared in advance before the arrival of patients. This kind of drug treatments is so-called anticipated treatments. At this hospital, currently, almost all treatments for patients without consulting an oncologist are anticipated. Oncologists transfer the prescriptions of this patient type several days before the treatment date. For the preparation of anticipated treatments, the current practice at COL is that pharmacists can prepare up to 48 hours in advance before the use of that treatment. For patients who need to see a doctor, their drugs may be anticipated depending on the molecules of their treatments. Determinants for the selection of molecules to be anticipated include the prevalence of molecules, the validity duration.

The obvious advantage of this policy is that some patients can get their drugs as soon as they arrive the infusion area at HDJ (if nurses and chairs are available) and hence their waiting time is reduced significantly. However, this policy results in the wastage of some drugs because sometimes patients cannot arrive HDJ due to the health problems, or the blood test result indicates that they are unable to get the treatment, and hence impose a cost for this policy. For drugs that are not administered for patients, they are returned to the pharmacy and the pharmacists will decide whether the drugs can be redistributed for other patients in case their treatments have the same molecules as well as dosage.

According to this drug preparation policy, we can classify patients at HDJ into different patient types with different routines at HDJ. In particular, we consider three patient types: Non-consultation patients (NC type), Consultation Anticipated patients (CA type), and Consultation Non-anticipated patients (CN type). NC type includes patients who arrive HDJ to get their chemotherapy treatments without seeing an oncologist. For patients who have an appointment with an oncologist, if their treatments are anticipated, we classify them into CA type. Otherwise, they are grouped into CN type. Although CN and CA patients go through similar processes at HDJ, their waiting time can vary significantly as a result of the drug preparation policy.

4. Simulation study

In this section, we implement a simulation study for chemotherapy patient flows. The main objective of this simulation is to mimic the current patient flow at HDJ to evaluate the performance of the current system. Therefore, it is necessary to take into consideration various characteristics and information of the current system at HDJ. In particular, this simulation work will consider four processes: check-in process, consultation process, drug preparation process and infusion process. Resources for the simulation include receptionists, pharmacists, nurses, treatment chairs/rooms, and consultation rooms. Based on the simulation results, we can estimate the average patient waiting time, the average time in the system, as well as the utilization rate of hospital resources.

4.1. Data collection

The data for the simulation are gathered from three sources: historical data, time study, and expert opinions. The information of the capacity of the current system is obtained by the field observation and discussion with nurses. Historical data of chemotherapy treatments at HDJ are collected from the scheduling system for the period from 29/01/2018 to 23/02/2018 (4 weeks) corresponding to 1427 treatments. The information collected from historical data for each treatment includes treatment date, expected infusion starting time, expected infusion duration, consultation or not, treatment protocols, and the use of treatment chairs and rooms. This information allows us to estimate various parameters for the simulation model, such as the patient arrival rate, the patient mix, and the expected treatment length. Other parameters for the simulation models, especially processing time of various processes are collected by discussing with nurses and time study.

Patient Arrival and Patient Mix

Patients arrive HDJ by the appointment time informed by nurses. By looking at the historical records of the scheduling system, we collect the average number of appointments for each working hour, from 8 AM to 4 PM. Although the arrival time of patients is fixed by HDJ, the real arrival time is random. Therefore, we employ the Poisson process to model the arrival time for patients. The fact is that the patient arrival rates at HDJ vary throughout a day, hence a non-homogeneous Poisson process will generate more accurate simulation results than a homogeneous process. The detailed patient arrival rate is presented in *Figure 2*.

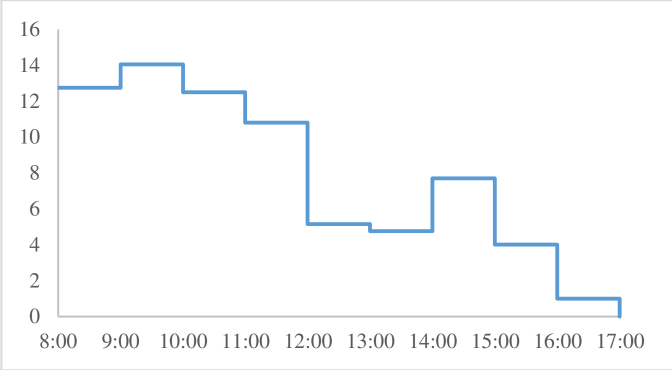

Figure 2: Patient arrival rate throughout a day (patients/hour)

As mentioned above, this simulation study considers three patient types with different routing: NA type, CA type, CN type. We extract the percentage of these patient types from the scheduling records. In general, the ratio for NC, CA, and CN is 38%, 13%, and 49% respectively. However, if we fix this ratio for the whole day, the simulation result may be incorrect compared with the current practice. In fact, CN patients are expected to spend long time at HDJ because they need to see a doctor and wait for their drugs to be prepared by the pharmacy before getting the treatment. As a result, their appointments are scheduled not too late so that all patient treatments must be finished before the closing time (19h30). Therefore, in this simulation study, the patient mix is further classified into two intervals: before 12h and after 12h. It can be seen in *Table* 2 that the ratio of NC and CN changes significantly in two intervals.

Table 2. Patient mix

Patient type	NC	CA	CN
Before 12h	34%	13%	52%
After 12h	51%	16%	34%

Nurse shifts and capacity

At the HDJ of COL, nurses work according to five different shifts and the planning for each nurse is determined for the whole week. The duration of each shift is 7 hours and 8 minutes, including a 20-minute break**.**

Table 3. Nurse shifts at HDJ

Shift	Start time	End time	Number of nurses/shift
1	7h30	14h38	1
2	8h00	15h08	3
3	9h00	16h08	3
4	10h22	17h30	2
5	12h22	19h30	3

In addition to the nurses taking care of patients, HDJ has one nurse to be responsible for taking administrative works (receive phone calls, schedule new requests). This nurse will not be taken into account in the simulation model because she has no impact on the patient flow. Based on our observation at HDJ and discussion with nurses, we have the number of nurses available for different shifts presented in *Table* 3. To simplify the simulation model which will be described below, we assume each nurse work 7 hours/day and without a break.

Based on the information of shifts as well as the number of nurses for each shift, we have the nursing capacity presented in *Figure 3*. It can be seen that the nursing capacity achieves its maximal value for the period from 12h30 to 14h30.

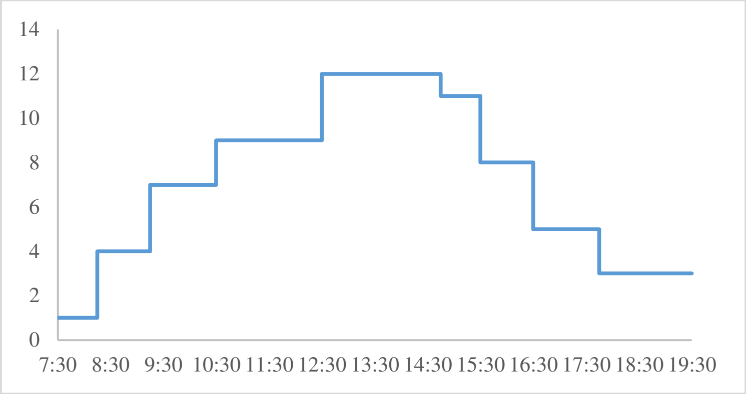

Figure 3. Number of nurses during one day

Other resources

Other resources and their capacity are listed in *Table 3*. Currently, the pharmacy of COL is responsible for preparing treatment drugs for both inpatient units and the HDJ with five technicians. In average, treatments of HDJ patients account for 70% the total number of treatments prepared by HDJ. Therefore, to simplify our simulation model, we assume that there are three pharmacists who prepare drugs for patients of HDJ.

Table 4. Other resources and their capacity

Resources	Capacity
Receptionists	2
Pharmacists	3
Consultation rooms	6
Treatment chairs	14
Treatment rooms	18

Processing time for different services

We have five processes in the patient flow: Check-in process, Consultation process, Drug preparation process, Pre-Treatment process, and Treatment process. The duration of each process for the simulation is determined based on three sources of data: Time study, historical data, and discussion with experts (nurses, oncologists, pharmacists).

Table 5. Processing time of different processes

Process	Data source	Proposed distribution
Check-in Time	Time study	UNIF(4,10)
Consultation Time	Expert opinion	TRIA(10,20,30)
Drug Preparation Time	Expert opinion	TRIA(35,45,55)
Pre-Treatment Time	Expert opinion	UNIF(10,15)
Infusion Time	Historical data	Empirical
Discharge Time	Time study	UNIF(2,4)

4.2. Simulation assumptions

Besides practices mentioned above, in this simulation, we have some assumptions to simplify the model.

Assumption 1: The infusion time for patients are only generated based on historical data.

Assumption 2: Oncologists are always available, and their specialty is not taken into account.

Assumption 3: Nurses are used as pool resources.

Assumption 4: No-show patients are not considered. The blood tests are always sent to HDJ on time.

The infusion time for each patient depends not only on treatment protocols but also on other factors, such as patient's health status, patient's weight. Therefore, Assumption 1 allows us to simplify our simulation by assuming that infusion duration is random and follows historical data. Assumption 2 means that patients can see their oncologist as soon as a consultation room is available. This assumption also confirms Assumption 1 in which patient's cancer type is not considered.

In practice, nurses are assigned to different treatment areas to manage patients better and each nurse is usually responsible for a patient from the pre-treatment process to the discharge process. However, during some busy time, nurses in different areas can help each other so that the intervention cannot be delayed too long. Therefore, Assumption 3 is reasonable in this case.

4.3. Simulation model

The simulation model is built using Arena version 15. To measure the waiting time of patients correctly, we use two entities in the simulation model: patient entity and information entity. This method is necessary to measure the waiting time of patient type CN who spend much time on waiting for their treatments to be prepared by pharmacists. The waiting time for each patient is the total waiting time at each process. The simulation model is replicated for 50 runs and results are collected to validate the model. We employ two performance metrics to validate the simulation model: Average time in the system, and average waiting time. Due to limit access to the database, we cannot use historical data to validate the model. Instead, we validate the simulation model by discussing results with nurses and oncologists at HDJ.

Table 6. Performance measures of the simulation model

Performance measures	Mean value	Half Width
Total time in service (minutes)	205.3	5.9
Total waiting time (minutes)	56.9	6.6

Table 7. Mean waiting time for different services

	Mean value
Waiting time for drug preparation (minutes)	30.0
Waiting time for chairs (minutes)	21.7
Waiting time for other services (minutes)	5.2

4.4. Discussion

Based on the simulation result, we observe that most of their waiting time is of the drug preparation process and wait for the availability of treatment chairs. This result confirms the practices at HDJ. During peak time (around 11h30), there are no available chairs and patients need to wait even though their treatments are available. The cause of this effect is the high arrival rate of patients during the morning as can be seen in *Figure 1*.

Therefore, to reduce total waiting time, we can modify the current scheduling policy at HDJ to achieve a more balanced utilization of treatment chairs, and then we can reduce the waiting time for treatment chairs that accounts for 40% of total waiting time.

5. Experiments

In this section, we test the impact of different policies on the patient waiting time. Based on the observation at HDJ as well as simulation results, patient waiting time is mostly contributed by two factors: waiting time for the preparation of treatment drugs and waiting time for available chairs. In fact, the treatment chairs at HDJ are fully utilized during the period from 11h to 13h due to the high arrival rate in the morning. As a result, we propose two policies to the current practice at HDJ to reduce patient waiting time: modify patient arrival rate and an increase the percentage of anticipated patients. The first modification can be easily implemented by the person who makes an appointment for patients. In contrast, the implementation of the second policy needs much effort from the hospital.

5.1. Scenario analysis

Scenario 1: Modify patient arrival rate

Based on the field observation, we find that the current patient arrival rate is unbalanced throughout the day, and in consequence, the chair utilization during some periods is almost full. This issue causes inefficient use of nurses as well as long patient waiting time to get available chairs at this moment. In this experiment, we change the patient arrival rate to have a more balanced pattern of the patient arrival. The arrival rate of CN and CA patients remains unchanged in this experiment because these patient types need a consultation and hence their appointment time also depends on the planning of oncologists. Only the arrival of NA patients is modified in this experiment because their appointment times do not involve the availability of oncologists. Historical data show that 60% of NA patients has infusion appointment in the morning. In this experiment, we decrease this ratio by moving more appointments of this patient type to the afternoon session. In particular, we propose two cases in which the percentage of NA patients for the morning session accounts for 20% and 40% the total number of NA patients of the whole day. In addition, these patients are distributed evenly throughout the morning and the afternoon sessions. *Figure 4* compares the patient arrival rate before and after the modification.

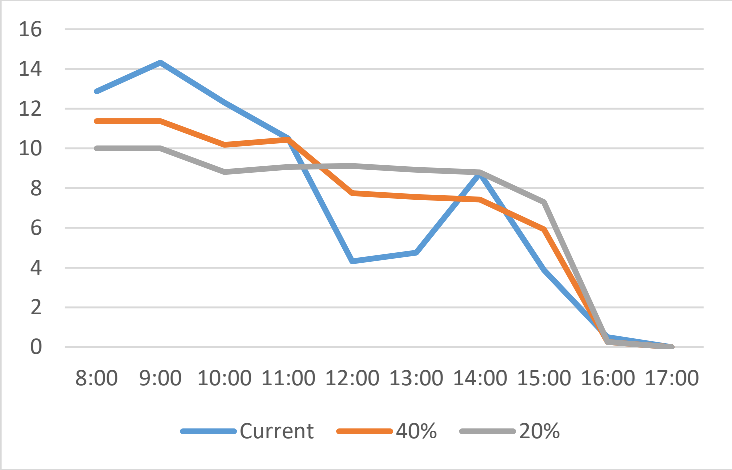

Figure 4. Current and modified patient arrival rate at HDJ

The simulation results of this policy are presented in *Table 8*. It can be seen that the total time in service and waiting time is improved when the arrival rate is modified by Policy 1. The reallocation of NA patients with the ratio 20% is statistically better than the current practice at HDJ. Thanks to more balanced patient arrival, patients spend less time waiting for available chairs.

Table 8. Performance measures of the system with Policy 1

	Current (60%)		40%		20%	
Performance measures	Mean	HW	Mean	HW	Mean	HW
Total time in service (minutes)	205.3	5.9	199.0	5.7	193.7	5.5
Total waiting time (minutes)	56.9	6.6	46.3	5.5	43	6.4

Scenario 2: Increase the ratio of anticipated treatments

In this experiment, the ratio of anticipated treatment is increased compared with the current practice at HDJ. It should be noted that the patient arrival rates remained unchanged in this scenario. Obviously, this policy will result in a reduction in the mean waiting time for drug preparation. However, the implementation of this policy has a cost for the hospital because the number of wastage drugs will increase. In this study, we only consider the reduction in waiting time thanks to this policy. The cost analysis will be considered in future research.
Based on historical data, the ratio of anticipated treatment prepared by the pharmacy accounts for 50%. In this experiment, we increase this ratio to two levels: 60%, 70%. In fact, it is impractical to have a 100% anticipated treatment because some treatments are too expensive to be wasted. *Table 9* summarizes simulation results when Policy 2 is applied. It can be seen that there is no statistical difference in the total time

Table 9. Performance of the system with Policy 2

	Current (50%)		60%		70%	
Performance measures	Mean	HW	Mean	HW	Mean	HW
Total time in service (minutes)	205.3	5.9	204.8	5.1	201.9	6.4
Total waiting time (minutes)	56.9	6.6	50.5	5.6	43.3	6.3

Scenario 3: Modify patient arrival rate and increase the ratio of anticipated treatments

Two proposed policies have an impact on patient waiting time. While the first policy reduces the waiting for seizing treatment chairs, the second policy reduces waiting time for getting drugs. In this experiment, we apply two modifications at the same time. In fact, when we increase the percentage of anticipated treatments without modifying the arrival rates, there will be high pressure on the need for treatment chairs around the peak time. As a consequence, although the waiting time for drugs is reduced, patients spend additional time to get a treatment chair. Therefore, the combination of these two policies will generate much better results for the current system. *Table 10* summarizes simulation results of Policy 3 in which 20% of NC patients are allocated for the morning session, and the percentage anticipated treatments are 70%. It can be seen patient waiting time in reduced by 50% compared with the current system.

Table 10. Performance measures of the system with Policy 3

	Current		**Improved**	
Performance measures	Mean	HW	Mean	HW
Total time in service (minutes)	205.3	5.9	188.5	6.1
Total waiting time (minutes)	56.9	6.6	29.0	4.6

6. Conclusion and future works

Patient waiting time in chemotherapy treatments is considerable in some cases and has a negative impact on the quality of care. This study uses DES to analyze the current system of an oncology center in Lille (France). The simulation model integrates various hospital resources and involved processes of chemotherapy patient flows. Simulation results show that the patient waiting time is mainly caused by two reasons: time for drug preparation and time for available chairs. Three policies are proposed to improve the performance of the current system: Simulation results show that Policy 3, which is a combination of Policy 1 and Policy 2, can reduce patient waiting time significantly. This simulation study is a baseline for future works of authors. In particular, the patient arrival rate can be solved optimally by combining simulation and a mathematical model to minimize the patient waiting time.

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Biographies

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