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Comparison between Outpatient Appointment Scheduling and Chemotherapy Outpatient Appointment Scheduling

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ABSTRACT

Healthcare management has received tremendous interest among researchers as it deals with human health. In this paper, two applications of scheduling on healthcare systems are studied. These two applications are outpatient appointment scheduling and chemotherapy outpatient appointment scheduling. We hold a scientific comparison based on computational models between the two appointment systems to investigate common and distinguishing features. The comparison is supported with two integer programming models computing the appointment times for patients. The two models are coded using CPLEX solver followed by numerical analysis of the results. The comparison findings are outpatient appointment problem has rich literature, whereas the chemotherapy outpatient problem has limited literature. Moreover, the appointment scheduling of chemotherapy outpatient units differs from outpatient clinics in some characteristics such as variability in treatment length, multiple steps in treatment and shared resources. On the other hand, the two systems have some common characteristics such as objectives and uncertainty in some parameters.

1. Introduction

Healthcare management derives its importance from dealing with human life. Countries worldwide spend large budgets on healthcare services, for instance, the USA spends about 17.9 % of its GDP (Gross Domestic Product) on healthcare, whereas, Egypt (as a developing country) spends about 4.7% of its GDP [1] on healthcare. Healthcare systems face a lot of challenges because of limited operating resources, high cost of medical technology and medication, high customer expectations towards

service quality, shortage in planning and management decision tools especially with the increasing complexity of health care systems, and increasing demand. Demand for healthcare systems is expected to increase dramatically due to increase in life expectancy and population rates. Life expectancy is projected to increase from an estimated 72.7 years old in 2013 to 73.7 years old by 2018, bringing more than 10% increase to the total global population [2]. This projected demand increase should be faced with a concurrent staff increase; nevertheless, the resources, facilities, and staff seem to be stationary (figure 1). Consequently, hospitals and private clinics are more

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conscious of the need to efficiently use their limited resources, which urges healthcare systems researchers to increase emphasis on the process optimization in order to control and minimize operating costs and improve the delivered services quality.

Outpatient clinic is a facility where patients come to have a consultation and receive treatment. It can be a part of the hospital or a private clinic. In this paper two disciplines of healthcare are considered from operations research and operations management perspectives.



Fig. 1. Doctors (per 1,000 populations) as compared with the total world population (millions) (adapted from [2])

The two disciplines, namely, the outpatient clinics and the chemotherapy outpatient units are basically appointment systems. Both systems provide care services for patients, starting from optimizing appointment rules, managing patient flow, service, quality control, sequencing patients, and no-shows and walk-ins treatment. On the other hand, every system from the two systems has some distinct characteristics, for instance the chemotherapy system has a cyclic behavior. In other words, every patient has a strict treatment protocol specified by the oncologist. That protocol contains dose prescription and its duration. For example, oncologist specifies for patient a certain dose. This dose for example is given every 21 days along 7 times; moreover, the oncologist may adapt the dose or the treatment length according to some considerations such as the lab results or recovering of the patient.

2. Outpatient Clinic Scheduling

Outpatient scheduling systems are used to manage all the resources efficiently, to minimize doctors idle times and patient waiting times, to sequence patients in a fair way, and to match the demand with the clinic capacity. All of these aspirations are emerging in what so called appointment system. Appointment system in outpatient clinics consists of acquiring three steps: approving an appointment rule, patient classification

strategy, and tactics to facing uncertain actions such as walk-ins (a patient comes without an appointment) and no-shows (a patient booked an appointment, but did not come). These three components of appointment systems somehow have been studied in the literature. As early as 1952, Bailey [3], Lindley [4], and Welch and Lindley [5] are the first works in outpatient appointment scheduling. After that progression of research are published until now. Because the literature in outpatient scheduling is rich, we suffice with two comprehensive review articles; the first is about review of literature about outpatient scheduling in health care by Cayirli et al. [6] and the second is about appointment scheduling in health care by Gupta et al. [7]. Cayirli et al. [6] provide a comprehensive review of outpatient appointment scheduling emphasized with methodologies taxonomy and research directions. Gupta et al. [7] focus on reviewing the appointment scheduling problems considering three topics; the access rule, encounter start times, and approaches for handling differences between the scheduled and realized supply and demand. For example, The access rule can help to make patient classification according to such priority, encounter start times determine the day and time for both staff and patients, and approaches for handling differences between the scheduled and realized supply/demand adapt the tardiness of both the service provider and patient, no-shows, and walk-ins [7] Gupta et al. [7] highlight the importance of electronic medical records in industrial engineering research.

2.1. Problem Definition

The problem of outpatient scheduling is to find an efficient, general, and a robust appointment system for both public and private clinics to satisfy a desired objective represented in minimizing both patient waiting time and staff idle time. Although the outpatient appointment scheduling problem is a dynamic problem, most of the literature considers it as static [6]. The heterogeneity between static and dynamic configurations is backed to decisions timings. If all decisions are taken before the clinic starts its daily chronicles, it's a static handling, otherwise, it is dynamic. In a simple way, an outpatient clinic can be treated as a simple queue with a single doctor and exponential service time under the punctuality assumption for both the doctor and patients. The majority of literature regards the problem as a queuing system, but in this paper, we formulate the outpatient clinic as linear program. There is a general problem among outpatient services that no two patients are the

same in health degree or in age, also no two doctors are same in delivering the same service. So it's a challenge to develop a universal model for all clinics. To fulfil a robust management both quantitative besides qualitative methodologies should be satisfied. Examples of quantitative and qualitative methodologies are mathematical and statistical analysis, and experience and judgment respectively. Developing and implementing an appointment system will minimize crowding in waiting halls, smooth staff and patient flow, provide preference options for both staff and patients, and increase the patient satisfaction.

2.2. Mathematical Formulation

To understand the outpatient scheduling problem, a simple integer linear programming model is introduced with the following assumptions and notation:

1. The model is deterministic.
2. The consultation time of each patient is estimated in advance.

Table 1: Notation 1

P	Set of patients
T	Number of slots on the day ($t=1..T$)
CT_i	Consultation duration for patient i , minutes
w_i	Opportunity loss of patient waiting
v_i	Penalty of doctor idle time
P_i^a	Actual patient arrival time for patient i
D_i^a	Actual time slot the doctor starts consultation for patient i
x_{it}	Binary decision variable, 1 if the consultation of patient i is started in time slot t , 0 otherwise

$$\min \sum_{i \in P} \sum_{t=1}^T CT_i (w_i (t - P_i^a) x_{it} + v_i (t - D_i^a) x_{it})$$

Subject to

$$\sum_{t=1}^T x_{it} = 1 \quad \forall i \in P \tag{1}$$

$$\sum_{i=1}^P x_{it} = 1 \quad \forall t \in T \tag{2}$$

The objective function measures and minimizes the weighted sum discrepancy between patient actual arrival and his assigned time slot t and also between the doctor idle time and each time slot. Constraint 1 strictly guarantees that each patient i is consulted once

in all the time slots. Constraint 2 strictly guarantees that in every time slot, one patient is consulted.

2.3. Computational Example

This model is coded using IBM ILOG CPLEX 12.2 for the following parameters in table 2:

Table 2: Values of the model parameters

P	30
T	30
CT_i	[14,15,12,13,17,18,18,15,20,10,12,11,9,8,7,16,13,14,15,12,15,19,18,17,17,18,19,20,21,21]
w_i	20 for patient i
v_i	5 for patient i
P_i^a	[0,0,0,0,0,0,0,0,0,1,1,1,1,1,1,1,1,1,2,2,2,2,2,2,2,2,2,2]
D_i^a	[1,2,3,4,5,6,7,8,9,10,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29]

If an outpatient clinic of one doctor, the number of patients that have called the clinic or visited the clinic to reserve is 30. The 30 patients need 30 consultation slots. If the consultation time for each patient is 15 minutes, the clinic working hours $30 \times 15 / 60 = 7.5$ hours. In other case, if the clinic working hours are strict particular hours, in that case, the clinic receptionist should receive a limited number of appointments and postpone the rest to the next working day. When a patient waits long in the clinic, a psychological talk initiates in the patient mind not to target this clinic again or transfer this pessimistic attitude to another candidate or the patient can cancel his appointment. In this case, an opportunity loss occurs for the doctor. This opportunity loss w_i can be expressed by a value 2 which can represent 2 Egyptian pounds loss for each patient.

Similarly, v_i is the penalty of the doctor being idle. This idleness can be represented by a penalty 1 LE for each time-slot idleness. The actual consultation duration CT_i is used for calculating the objective function which measures the effect of patient waiting and doctor idleness. P_i^a is the actual patient arrival in time slots units. The first 10 patients arrive before the doctor starts the consultation, the second 10 patients arrive at the first time slot, and the last 10 patients arrive at the second time slots and wait in the clinic until taking their turns. About D_i^a , there is no idleness for the first 10 patients, but the rest of the 20 patients, the doctor get idle one time slot. At these conditions, the

objective function value is 6070. If all the patients arrive in the scheduled time slots and the doctor starts without idleness, the objective function value becomes (-4850) which is the minimum idle value. If all patients come before the first consultation slot start by one slot whereas no doctor idleness, the objective value will become 2465. So, the objective function improves when the patient is scheduled to come in his/her appointment time than coming on the beginning of the clinic time, as a result, the clinic revenue increases.

3. Chemotherapy Outpatient Clinic Scheduling

The chemotherapy outpatient clinic planning and scheduling is a complex problem. Many factors feed this complexity, such as the variability inherited in all the stages of the oncology and infusion process and uncertainty in some of its parameters. Cancer is the leading cause of morbidity and mortality worldwide, with approximately 14 million new cases and 8.2 million cancer related deaths in 2012 [8,9,10]. This number is expected to increase to reach 24 million by 2035 [8,9,10]. The number of people living beyond a cancer diagnosis reached nearly 14.5 million in 2014 and is expected to rise to almost 19 million by 2024 [11]. The demand for oncology services in the United States only is expected to increase from 41 million in 2005 to 61 million in 2020 [12]. In 2015, an estimated 1,658,370 new cases of cancer will be diagnosed in the United States and 589,430 people will die from the disease [11]. More than 60 percent of the world's new cancer cases occur in Africa, Asia, and Central and South America; 70 % of the world's cancer deaths also occur in these regions [11]. In Egypt, about 108,600 new cancer patients are diagnosed yearly whereas about 72,300 patients dying from cancer yearly [13].

Nothing can be manipulated in healthcare systems in general and cancer treatment in particular without considering the cost. It has been estimated that the new cases of cancer diagnosed in 2009 cost the world \$286 billion that year alone [14]. Total expenditures in the United States reached nearly \$125 billion in 2010 and could reach \$156 billion in 2020 [11]. About Egypt, the monthly treatment expenditures per patient are \$1600. This is more than eleven times greater than the average monthly household income [15]. As a result, the cancer treatment process needs a wise management system to exploit all the limited resources of clinics and treatment centers.

Cancer is cured in a systematic way, using surgery, radiotherapy, and chemotherapy. These three

systematic treatments can imply other treatments such as hormonal therapy and immunotherapy. Chemotherapy uses drug infusion to kill the cancerous cells with controlling the side effects. One of the problems related to chemotherapy management is the planning and scheduling problems. In other words, assigning the treatment days for each patient as soon as the oncologist plans the treatment, also, assigning the starting time of treatment on the assigned day. Not only assigning the treatment time for the patient is the problem, but also providing quality treatment service is desirable. This quality requires an efficient assignment of different resources to patients, such as chairs/beds, nurses, pharmacists, labs, and so on.

The chemotherapy outpatient scheduling problem is a complex problem [11,13,14,15,16,17]. The complexity is backed to several factors. These factors can be stated as follows:-

- High variability in resource requirement such as nurses, oncologists, chairs/beds, and pharmacists.
- High variability in treatment process activity times such chart review, drug preparation, and drug infusion.
- The cyclic nature of chemotherapy treatment plans.
- Appointment cancellation uncertainty.
- Add-ons uncertainty (some unscheduled patients may come).
- No-show uncertainty (a person who has made an appointment, but neither keeps nor cancels it).
- Real-time arrival and departure of appointment requests.
- Huge demand for treatment under limited resources.

For more details about the chemotherapy outpatient planning and scheduling, Heshmat and Eltawil [20] review the literature of chemotherapy outpatient planning and scheduling. They classify the literature into three categories; patient appointment scheduling, nurse assignment, and operational performance measure. Also, they provide research gaps, research directions, and a solution framework.

3.1. The Patient Flow and Curing Process

Figure 2 depicts the curing process and patient flow in a typical chemotherapy outpatient clinic. As soon as patient arrives, a medical assistant provides the reception service to him/her. If the patient is new, the scheduler gives him/her a further appointment time; otherwise the patient information is checked. If the

patient has performed the lab tests which had been determined before by the oncologist, he/she waits until checking the chart and making a consultation with a scheduled oncologist otherwise the patient performs the lab tests in the oncology center. When the patient sees the oncologist, based on the lab results and the patient chart, the oncologist decides the chemotherapy regimens from the different chemotherapy protocols and also the dosage amount. Then the patient waits again until drug preparation. After that, a scheduled nurse infuses the dose into the patient, and monitors him/her. If any complications occur, the nurse has to deal with these complications until the patient recovers again, and finally the patient is disposed outside the clinic.

Fig. 2. Patient Flow in Chemotherapy Unit [20]
3.2. Problem Formulation

To understand the chemotherapy outpatient problem, a mixed integer programming model is introduced under the following assumptions and notation:

1. Deterministic model
2. No nurse or chair constraints
3. Unconstraint infusion time
4. No acuity level
5. No oncologist idleness

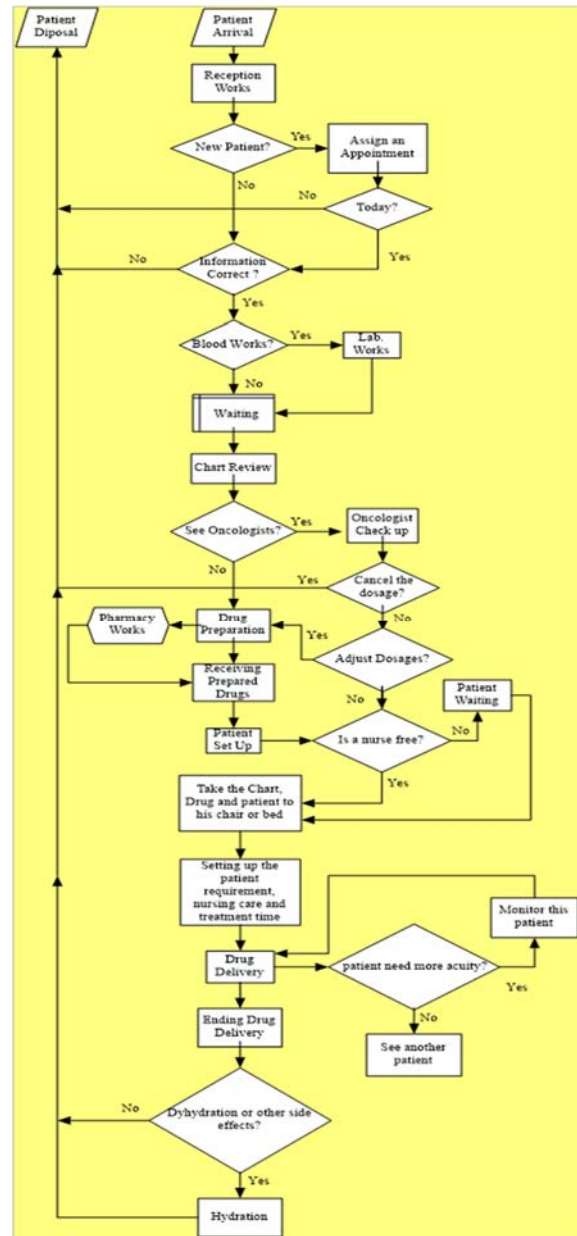
Table 3: Notation 2

P	Set of patients
T	Number of slots on the day ($t=1..T$)
CT_i	Consultation duration for patient i , time slots
m_i	Weight of patient i waiting
n	Weight of the makespan
DP_i	Drug preparation time for patient i
y_i	Drug infusion starting time for patient i
x_{it}	Binary decision variable, 1 if the consultation of patient i is started in time slot t , 0 otherwise

$$\min \sum_{i \in P} \sum_{t=1}^T (m_i(y_i - x_i - DP_i) + nT)$$

Subject to

$$\sum_{t=1}^T x_{it} = 1 \quad \forall i \in P \tag{1}$$



$$\sum_{t=1}^P x_{it} = 1 \quad \forall t \in T \tag{2}$$

$$y_i \geq x_{it} + CT_i + DP_i \quad \forall i \in P, t \in T$$

$$y_i \geq 0 \tag{3}$$

$$x_{it} = \begin{cases} 1 & \text{If a patient } i \text{ is consulted at a time slot } t \\ 0 & \text{Otherwise} \end{cases}$$

The objective function minimizes the weighted sum of patient waiting time and the makespan. Constraint 1 assigns one patient consultation in all the time slots. Constraint 2 assigns only one patient in each time slot. Constraint 3 guarantees that the drug infusion starts after consultation and drug preparation.

3.3. Computational Example

This model is coded using IBM ILOG CPLEX 12.2 for the following parameters in table 3:

Table 3: Values of the model parameters

P	20
T	20
CT_i	[1.2 2 1 2 1 1.4 1 1 1 1 1.2 2 2 2 2 2 1.1 1 1 1 1]
m_i	[1 1 1 1 1 1 1 1 1 1 1 2 2 2 3 1 6 5 4 7 8]
n	1
DP_i	[1 2 1.2 1.3 1.1 1.2 1.3 1.4 1.2 2 1.1 1.3 3 2 4 2 2.5 2 1.5 1.2]

The objective function value is 2162 and the variables results are as follows:

Each patient i is assigned to a time slot t , but the infusion starting time differs from patient to another, $y = [3:2 \ 5 \ 3:2 \ 4:3 \ 3:1 \ 3:6 \ 3:3 \ 3:4 \ 3:2 \ 4 \ 3:3 \ 4:3 \ 6 \ 5 \ 7 \ 4:1 \ 4:5 \ 4 \ 3:5 \ 3:2]$

In other words, if the time slot is 5 minutes and the clinics begins at 1:00 PM then the infusion starting time is $y = [3:12 \ 5:00 \ 3:12 \ 4:18 \ 3:06 \ 3:36 \ 3:18 \ 3:4 \ 3:12 \ 4 \ 3:18 \ 4:3 \ 6:00 \ 5:00 \ 7:00 \ 4:06 \ 4:30 \ 4:00 \ 3:30 \ 3:12]$

Although, the MIP model seems to be simple since the assumptions, it has 400 binary variables, 440 constraints, and 1600 non-zero coefficients. But the computation time for such daily computation is 0.53 seconds using PC Core i7 3.4 GHz, 4 GB Ram. Imagine the model volume, if no assumptions are borne in considerations. It's really a complex problem, trade-off between computation time and optimal solution may be an acceptable approach.

4. Distinguishing Features

All the healthcare systems have the same targets, is to deliver the service to patients in a high quality and minimum possible cost. It seems that the two objectives are conflicting, but this the common objective of all healthcare applications. Chemotherapy outpatient clinics differ from the general appointment clinics in some characteristics. One of them is the cyclic nature of chemotherapy. Every patient receives a certain dose every prescribed number of days. The cycle length is determined by the oncologist according to the type of cancer and the patient clinical status. Another difference between chemotherapy outpatient clinics and general clinics is the variability in

treatment length. Treatment length varies between 15 minutes and 8 hours. Table 4 summarizes and compares the distinguishing features between outpatient and chemotherapy outpatient problem characteristics.

Table 4: comparison between outpatient and chemotherapy outpatient characteristics [Adapted from [18]]

Problem Characteristic	Outpatient Appointment	Chemotherapy Appointment
Multiple steps within a treatment	N	Y
Real time Uncertainty	Y	Y
Uncertainty due to last minute changes	Y	Y
Objective to maximize resource utilization	Y	Y
Objective to minimize wait times	Y	Y
Large variability in treatment lengths	N	Y
Shared Resources	N	Y
Appointment Request	By the patient	By the oncologist

5. Conclusion

This paper has provided a comparison based numerical examples for both outpatient appointment scheduling and chemotherapy outpatient appointment scheduling problems. It is clear that both problems are stochastic real problems and the chemotherapy outpatient problem is more complex than the outpatient appointment scheduling problem.

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