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Research Article

A Stochastic Mixed Integer Programming Model for Outpatient Appointment Scheduling considering late cancellation and physician lateness

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Abstract

Background Objective: Nowadays, the essentiality to provide services to outpatients has been grown in medical centers in developed and particularly developing cities. Outpatients are a kind of patients who register their appointment by requesting a specific website, telephone call or app before entering the medical centers and referring them to be visited within the prescribed time. To achieve optimal outpatient care, health centers must design and implement systems and policies that not only improve outpatient satisfaction but also minimize the costs of medical centers.

Methods: This paper develops a model that considers increasing the number of patients admitted, physician lateness and cancelation of outpatient appointments due to extreme delays. It formulates a stochastic mixed-integer programming model that decreases the costs by reducing outpatient waiting time, physician overtime, and physician idle time. It uses the sample average approximation that defines scenarios based on the model conditions. Moreover, it considers that outpatients may register their appointments but do not go to the medical center. It also formulates another essential factor, unpunctuality of outpatients (both earliness and lateness conditions).

Results: This paper defines some tests for the sensitivity analysis of the proposed model and then compares it with a model in the literature. These analyses were carried out using GAMS software which shows the results of the proposed model.

Conclusion: Finally, this article shows reviews and evaluations to prove its optimality and utility of the proposed model for using it in the real world.

Keywords: Outpatient Scheduling, Cancellation, Appointment Systems, Stochastic Mixed-Integer Programming

Background and Objective

In the United States from 1996 to 2006, outpatient medical center techniques were recognized very important, and their growth rate was 300%, while the rate of surgical centers remained virtually unchanged. In the past, many techniques required resources and types of equipment that were only available in hospitals, which, with the advent of technology and health services, there is no more lack of facilities such as laparoscopy, endoscopy, and laser surgery[1-2].

A period of the seasons when the number of people with diseases such as the flu is high, outpatient rates increase, which increases patients' waiting time in the queue and discontents them. Traditional operational management practices after brainstorm meetings often result in the number of nurses being divided into two divisions and serving in two separate locations. Whereas modern applied methods evaluate functional formulations, including queuing theory.

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Failure to pay attention to the time allocated for patient admission, even for less than 1 minute, will significantly increase patient waiting time. It will also happen that the rate of patients entering the hospital during shifts would not be the same, and during the day will be high or low[3].

From the perspective of operations management, there are various criteria for evaluating outpatient performance. Patient waiting times, the productivity of personnel and resources, patient (maximum capacity) efficiency, and overtime costs are essential criteria that are related to the price and quality of service delivery. However, deciding on these criteria can be complicated. Patients' waiting time and resource productivity will result in positive changes in one criterion while leading to adverse changes in the other one[2].

In revenue management, the demand for a particular resource is at a specific time. Requests cannot be achieved by resources alone. However, the need for regular patients arriving on a specific day can always be achieved on the next day. Another difference is that high-priority demand disappears if non-monetized[4]. Productivity is one of the critical factors in any business's success. In the case of a dental practice, scheduling plays a vital role in the ability to function. Patients appreciate that they receive services promptly because it demonstrates that action is important in its own time. However, even the most efficient scheduling can be devastated by patients who are late either by not attending their appointment or by canceling their appointment at the last minute[5]. In service systems, service providers want to minimize their costs with respect to the service's idle time, while customers are willing to receive the service with the least waiting time. To achieve these goals, service providers may schedule patients to enter by a shift schedule[6].

Project scheduling in the service industries is quite different from project scheduling in the manufacturing industries. Examples of project scheduling in the inclusive service industries are consulting projects, system startup projects, maintenance projects, and more. Consulting projects may also include annual auditing processes that must be performed by private company accounting in each public company. A system startup project may involve running a massive computer system in a company or running an extensive network. These types of projects can take many years. A maintenance project may be an annual major overhaul of a significant manufacturing facility, such as power generation. Such facilities may have to stop production for maintaining maintenance[7].

Two significant issues faced by almost all outpatient clinics are no-show and last-minute cancellation. If patients cancel their appointment at an appropriate time, the scheduler can replace new ones for canceled requests. However, if patients delay their appointment too late such that the system cannot replace a new patient, it is the no-show patient. Therefore, most papers addressing this issue focus on no-show and cancellation[8-10]. The likelihood of a patient being absent may be related to factors such as the patient's age, gender, and the number of previous appointments. Several reports have worked on reducing no-show. For instance, they send patients a reminder card or ask patients to remind them of their date. The highest no-show is among youth, men, and those with low socioeconomic status[11]. Deciding on the timing of an appointment is made by finding a specific time when the patient is about to begin the necessary care to optimize performance criteria. In outpatient scheduling systems that use the scheduling slots method, when a patient is calling, he or she is assigned a timetable that is scheduled according to the start time of a predetermined interval[12].

Erdogan et al[13] presented a stochastic integer programming model for dynamic sequencing and scheduling with a random server. The number of patients is also assumed to be uncertain. Patients are dynamically assigned when requested. They introduced a two-stage integer program[13]. Optimal random models or simulation models or queue models are used when the number of patients is specified, although the number of patients requesting an appointment is unclear. Regular patients are admitted during the day, but emergency patients are accepted without an appointment by taking some time. The purpose of the article is to minimize the cost of waiting time and overtime. Erdogan et al[13] used the L-Shape algorithm for solving the proposed model. Most stochastic integer programming models are based on the first come first served (FCFS) queuing system. Patients' sequencing is vital in scheduling. Patients who have to undergo surgery are divided into emergency and non-emergency units, which the appointment to non-emergency patients may be assigned several months later. How patients execute sequences is more important than the rules for scheduling patients. FCFS queuing system is not an optimal system if patients have different levels of disease. They formulated the problem of dynamic sequencing and scheduling as a randomly mixed-integer programming problem with binary decision variables and continuous decision variables, patient arrival time, and appointment time. The paper concludes that if the distribution of time of service and cost of patients is the same, the FCFS queuing system is appropriate.

Song et al[14] developed a model for examining the scheduling and designing of hospital turnover rules. It was done using Markov's theory. They used the optimization of shifts, inpatient rates, and patient waiting times as three criteria for hospital coordination and access. Their studies show that extending the time window of a shift, in particular, does not reduce congestion.

Deceuninck et al[15] investigated the scheduling of outpatients considering the time of the unpunctuality of patients and their no-show. Evaluation of patients' time distribution is deemed to be discrete. The time of acceptance of patients by physicians is random. The basis of the assessment in the paper is based on Lindley's statistical distribution of returns. It is an excellent way to predict patients' waiting times, doctors' idle time, and overtime. Deceuninck et al[15] solved their proposed model using the local search algorithm. The Markov chain was also used for patient waiting time, which in turn reduces the costs.

Jiang et al[16] studied the outpatient appointment scheduling considering the unpunctuality of patients by developing a stochastic programming model. The proposed model is based on Benders' decomposition method for obtaining optimal scheduling. Its purpose was to minimize patients' waiting time, physician idle time, and overtime. Jiang et al[16]compared two systems. System 1 considers the unpunctuality of outpatients while system 2 considers the punctuality of outpatients. They concluded that patients' no-show from their Schedule of system 1 was more effective than the Schedule of system 2.

The present study first defines the stochastic linear programming model of Jiang et al[16]. Then, it introduces some contributions such as delay probabilistic parameter, outpatient cancellation due to extremely delay, and designing conditions to accommodate more outpatients. We formulate the problem according to the mentioned contributions. We compare the new model with the model of Jiang et al[16]. Moreover, during the four stages of sensitivity analysis, we evaluate the optimality of the developed model. The evaluations and analyses are carried out by GAMS software.

For simplicity, we call the model of Jiang et al[16]. the “JTY model” and the model formulated in the present study the “new model”. We present the structure of the two mentioned models including the definitions, the assumptions, the rules governing them, and the limitations. Then, we perform sensitivity analysis conditions and display the results. Finally, discussions and suggestions are given.

Methods

In this section, we first describe the JTY model and then we add some new items and try to formulate them. The new model is a stochastic mixed-integer programming model. We also perform sensitivity analysis in four separate steps and compare the two models.

Model Description

It is assumed that at the start of a daily shift with the presence of a physician to serve patients who have been referred through an app, site, or telephone, N outpatients exist. The likelihood that patients who take an appointment cannot attend to the medical center is equal P_{ns} (The probability of no-show patient). However, since the unpunctuality of outpatients is also considered, the presence of outpatients falls within a range of time. It means that if the outpatient does not present at that range then he/she will be included for a no-show patient. The shift length is indicated by T. The amount of time a physician spends at a health center is precious time, so the idle rate for a physician is 1. If all outpatients are admitted in T periods, the physician may leave the medical center, but if the number of outpatients passes T, the physician will be added at a time that is shown by β. Also, outpatients' waiting time rates is α.

The parameter A_k is equal to the time given to the k^{th} patient and R_k shows the actual arrival time of the k^{th} patient. The unpunctuality of the k^{th} patient is equal to the difference of the outpatient's actual arrival time and the assigned time, which is equal to $u_k = R_k - A_k$. The parameter u_k is a probabilistic parameter, when outpatients come earlier than the assigned appointment time this parameter gets a negative value and when a patient has delay more than the assigned appointment time this parameter gets a positive value. However, the earliness or delaines is in a specific time range.

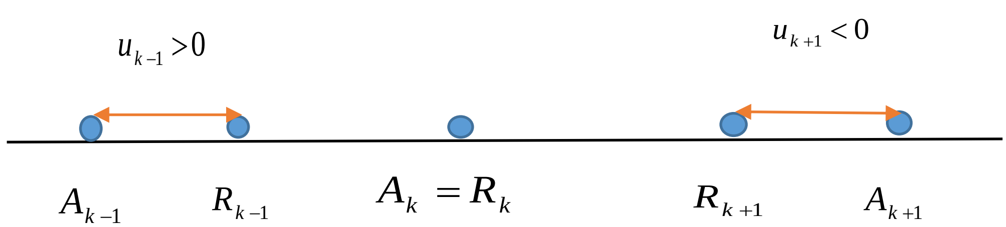

Figure 1. Arrival time range of unpunctual patients (16)

Figure 1 shows the unpunctual patients, which consists of two types. The variable X_k is the time between the k^{th} and $k+1^{th}$ outpatients' given times, which is $X_k = A_{k+1} - A_k$. Therefore the variable X_k forms a schedule for N outpatients. Factors that are dependent on time are listed below:

A_k : Given time to k^{th} outpatient

AD : Doctor's arrival time

R_k : The actual arrival time of the k^{th} outpatient

S_k : Start of the service time of the k^{th} outpatient

G_k : End of the service time of the k^{th} outpatient

Parameters that represent the time period are listed below:

ξ_k : The length of time of service to the k^{th} outpatient

u_k : The unpunctuality of the k^{th} outpatient

ud : Physician lateness time

The variables that represent the time period are listed below:

V_k : Direct waiting time of the k^{th} outpatient which will be calculated from arrival time

W_k : The waiting time of the k^{th} outpatient which will be measured from the actual arrival time

I_k : Physician idle time for the k^{th} outpatient

O : Physician overtime

X_k : Time between the given appointment times of the k^{th} and $k+1^{th}$ outpatients

M : A very large number

Q_k : A binary variable. The value is 1, if the patient is not eliminated. Otherwise the value is zero.

In this article, it is assumed that if the k^{th} outpatient was not on time and has delayed, and the $k+1^{th}$ patient arrives earlier than the k^{th} patient, the physician does not visit the $k+1^{th}$ outpatient. So the $k+1^{th}$ outpatient stays in perspective until the k^{th} outpatient is presented at the time interval set for the unpunctuality parameter values of the outpatients. The physician is also idle during this period.

The JTY model

This section first discusses the constraints and rules governing the model and finally describes the JTY model. Waiting time for the k^{th} outpatient (V_k) and physician idle time for the k^{th} outpatient (I_k) when outpatients arrive on shifts or on non-shifts, have monolith formulas.

The direct waiting time for the first outpatient to start daily appointments is according to Formula 1, as well as the length of time that the physician waits for the first outpatient to complete Formula 1. It can be seen that the direct waiting time of the first outpatient and the physician's idleness for that outpatient are calculated solely based on of the unpunctuality of the first outpatient.

$$(1): V_1 = (-u_1)^+ .$$

$$(2): I_1 = (u_1)^+ .$$

In the outpatient appointment system, different situations may occur that are summarized. One of the possible scenarios is shown in Figure 2.

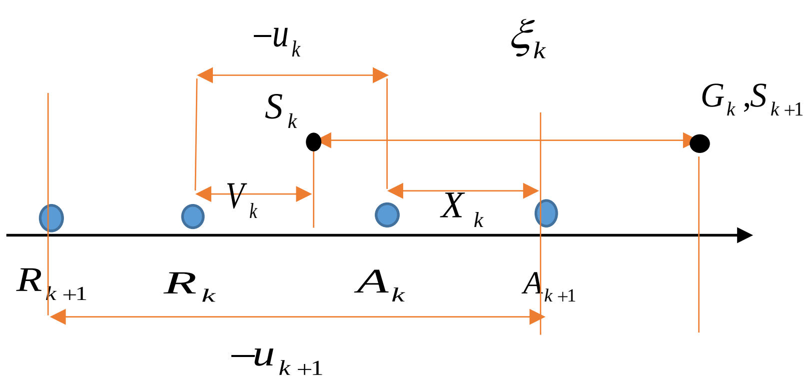

Figure 2. The k^{th} and $k+1^{th}$ patients arrive earlier than the actual appointment of the k^{th} patient (16)

In Figure 2, outpatient waiting time of the k^{th} outpatient is equal to the interval time between the start time of servicing and arrival time of the k^{th} outpatient. The relationships resulting from this form are as follows:

$$(3): V_{k+1} = S_{k+1} - R_{k+1} = -u_{k+1} + \xi_k - X_k - (-u_k - V_k) = V_k + \xi_k - X_k + u_k - u_{k+1}$$

.

It can be concluded from formulas 1 and 2 that V_k and I_k are in opposition. If the number of admissions is proportionate, the waiting time for outpatients is zero, while the physician's idle time may be greater than zero. If the arrival rate of patients is not appropriate, the physician will be always busy, and the waiting time of patients is not zero, and thus the physician's idle time will be zero. Therefore, the following relationship will be established for all outpatients:

$$(4): V_k \times I_k = 0.$$

As shown in Figure 2, for patients' waiting times, the following relation to physician's idle time can be stated:

$$(5): I_{k+1} = +u_{k+1} - \xi_k + X_k + (-u_k - V_k) = -V_k - \xi_k + X_k - u_k + u_{k+1}$$

.

The necessary waiting time for medical center is W_k. It will be calculated from the start of the appointment and has the following relation with the direct waiting time:

$$(6): W_k = \left(V_k - (-u_k)\right)^+.$$

The overtime of the physician is the difference between the total waiting time of the last outpatient, the length of his/her service, and the unpunctuality of the his/her, plus the sum of the time between the pre-outpatient appointments to the total time of that shift.

$$(7): O = \left(V_N + \xi_N - T + \sum_{k=1}^{N-1} X_k + u_N\right)^+$$

As described, the sample average approximation method is used to model the JTY linear programming model. The method is based on the scenarios considered for the model parameters. The model will be executed, where the values of the objective function will be collected for each scenario and divided by the total number of scenarios.

Based on the definition of rules and assumptions as well as the constraints, the JTY model is:

$$(8): JTY model: \quad (LP) \quad \min 1/Y \sum_{y=1}^{Y} \left[\sum_{k=1}^{N} \left(\alpha W_k^y + I_k^y \right) + \beta O^y \right]$$

$s.t.$

$$V_1^y \geq -u_1^y$$

$$V_k^y - V_{k-1}^y + X_{k-1} \geq \xi_{k-1}^y + u_{k-1}^y - u_k^y \qquad k = 2,3,\ldots,N$$

$$I_1^y \geq u_1^y$$

$$I_k^y + V_{k-1}^y - X_{k-1} \geq -\xi_{k-1}^y - u_{k-1}^y + u_k^y \qquad k = 2,3,\ldots,N$$

$$W_k^y - V_k^y \geq -(-u_k^y)^+ \qquad k = 1,2,\ldots,N$$

$$O^y \geq V_N^y + \xi_N^y - T + \sum_{k=1}^{N-1} X_k + u_N^y$$

$$V_k^y, I_k^y, W_k^y \geq 0 \qquad k = 1,2,\ldots N, \forall y = 1,2,\ldots,Y$$

$$O^y \geq 0 \qquad \forall y = 1,2,\ldots,Y$$

$$X_k \geq 0 \qquad k = 1,2,\ldots N-1$$

$\left(-u_k^y\right)^+$: This means that it can only hold values of zero or greater than zero.

The y index in model 8 represents the scenarios. As it is known in the objective function, the values of each scenario are summed and eventually divided by the number of scenarios.

Formulating the new model

At first, the lateness parameter of the physician and then the cancellation of the appointment due to extreme delays are examined. In this model, both the k^{th} outpatient direct waiting time (V_k) and the physician's idle time for the k^{th} patient (I_k) have unified formulas either outpatients arrive on their appointment or not.

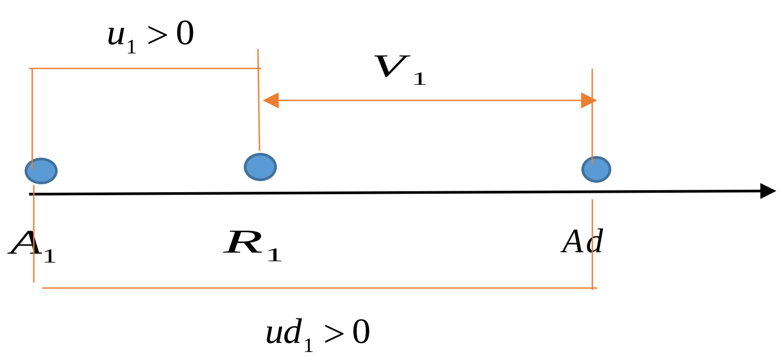

Figure 3. Waiting time for the first patient to receive service

It is shown in Figure 3 that the shift begins with the time given to the first outpatient. The index set for the physician lateness parameter means the effect the physician lateness has on the first patient as well as the timing of the appointment. In Figure 3, both the first outpatient and the physician are late, but the physician lateness time is longer than the first patient's delay. So the first outpatient must wait until the physician arrives at the medical center. It is clear that the waiting time for the first outpatient is equal to the time between the physician lateness and the first lateness outpatient. As a result:

$$(9): V_1 = (-u_1 + ud_1)^+ .$$

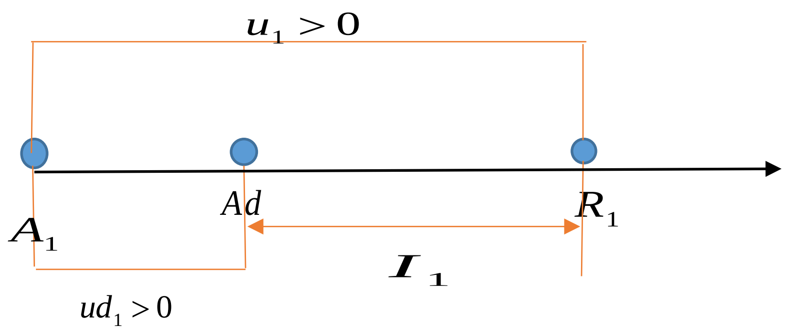

Figure 4. Physician idle time for the first patient

In Figure 4, both the first outpatient and the physician have delayed. However, the patient's delay is longer than the physician's delay. So the physician is ready to serve but the first patient has not arrived, and the physician has to wait. As can be seen, the physician's idle time is equal to the time between the delay of the first patient and the time that the physician arrives at the medical center. As a result:

$$(10): I_1 = (u_1 - ud_1)^+ .$$

The formulas described in Section 2.2 can be applied where the cancellation of the patient's appointment due to extremely delay does not happen. Figure 5 shows how the medical center cancels the outpatient's appointment.

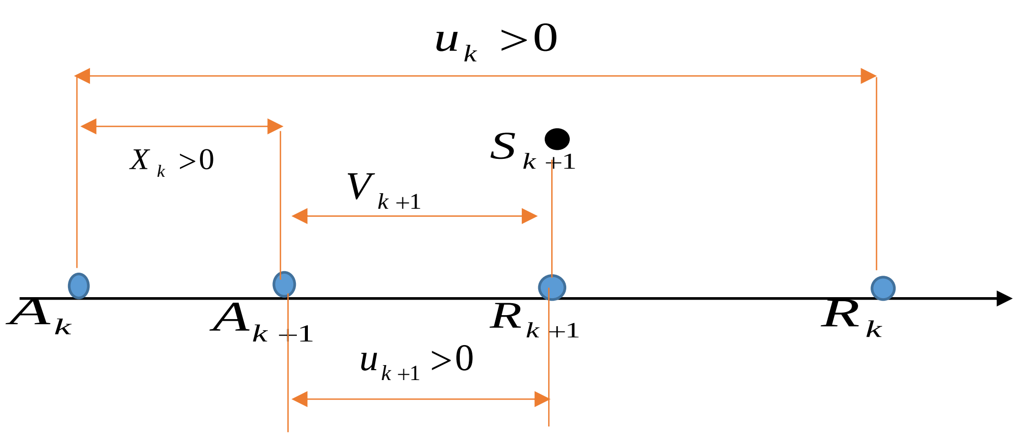

Figure 5. The k^{th} and $k+1^{th}$ patients arrive after the time appointment assigned for the $k+1^{th}$ patient

Figure 5 is a case in which the k^{th} outpatient arrives later than the scheduled time for its appointment and the $k+1^{th}$ patient has delay but k^{th} outpatient arrives later than the $k+1^{th}$ outpatient. This is where the medical center cancels the k^{th} outpatient appointment even if the k^{th} outpatient arrives, and the physician visits $k+1^{th}$ outpatient.

To obtain the formula in different outpatient admission conditions, there are two cases for k^{th} outpatient. If the binary variable Q_k gets a value 1, the k^{th} outpatient's appointment will not be canceled. Otherwise the variable will be set to zero and the appointment of the k^{th} outpatient will be deleted. According to Figure 5, the following formulas are listed below:

$$(11): u_{k-1} \geq -M.Q_k \ ,$$

$$(12): u_k \geq -M.Q_k \ ,$$

$$(13): X_{k-1} + epb \geq -M.Q_k \ ,$$

$$(14): u_{k-1} - X_{k-1} - u_k \geq -M.Q_k \ ,$$

$$(15): -W_k + M.Q_k \geq 0 .$$

In the Formula 13, the value of "epb" is very small. In fact, if the appointment of the k^{th} outpatient will be removed, the value of X_k should be greater than zero. When the k^{th} outpatient appointment is canceled, the $k+1^{th}$ outpatient waiting time and the physician's idle time for the $k+1^{th}$ outpatient must be calculated based on the $k-1^{th}$ outpatient direct waiting time and the physician's idle time for the $k-1^{th}$ outpatient. As a result, the Formula 3 is written under formulas 16 and 17 under two conditions of admission or cancellation.

$$(16): V_k - V_{k-1} - \xi_{k-1} - u_{k-1} + X_{k-1} + u_k \geq -M.(1-Q_k) \ ,$$

$$(17): V_k - V_{k-2} - \xi_{k-2} - u_{k-2} + X_{k-2} + u_k \geq -M.Q_k \ .$$

The Formula 14 indicates that it is an active constraint of the k^{th} outpatient delay time is greater than the sum of the interval times k^{th} and $k+1^{th}$ outpatient and also $k+1^{th}$ outpatient delay. The Formula 5 will be also written in formulas 18 and 19.

$$(18): I_k + V_{k-1} + \xi_{k-1} + u_{k-1} - X_{k-1} - u_k \geq -M.(1-Q_k) \ ,$$

$$(19): I_k + V_{k-2} + \xi_{k-2} + u_{k-2} - X_{k-2} - u_k \geq -M.Q_k \ .$$

According to the discussed formulas, the stochastic mixed-integer linear programming model is as follows:

(20) New model: (MIP)

$$min\ {}^{1}/_{Y} \sum \left| \sum (\alpha W_k^y + I_k^y) + \beta . O^y \right|$$

s.t.

$$V_1^y \geq -u_1^y + ud_1^y$$

$$V_k^y - V_{k-1}^y - \xi_{k-1}^y - u_{k-1}^y + X_{k-1} + u_k^y \geq -M.(1-Q_k^y) \qquad k = 2,3,\ldots,N$$

$$V_k^y - V_{k-2}^y - \xi_{k-2}^y - u_{k-2}^y + X_{k-2} + u_k^y \geq -M.Q_k^y \qquad k = 3,4,\ldots,N$$

$$I_1^y \geq u_1^y - ud_1^y$$

$$I_k^y + V_{k-1}^y + \xi_{k-1}^y + u_{k-1}^y - X_{k-1} - u_k^y \geq -M.\left(1 - Q_k^y\right) \qquad k = 2,3,\ldots,N$$

$$I_k^y + V_{k-2}^y + \xi_{k-2}^y + u_{k-2}^y - X_{k-2} - u_k^y \geq -M.Q_k^y \qquad k = 3,4,\ldots,N$$

$$W_k^y \geq V_k^y - \left(-u_k^y\right)^+ \qquad k = 1,2,\ldots,N$$

$$O^y \geq V_N^y + \xi_N^y - T + \sum_{k=1}^{N-1} X_k$$

$$u_{k-1}^y \geq -M.Q_k^y \qquad k = 3,4,\ldots,N$$

$$X_{k-1} + epb \geq -M.Q_k^y \qquad k = 3,4,\ldots,N$$

$$u_k^y \geq -M.Q_k^y \qquad k = 3,4,\ldots,N$$

$$u_{k-1}^y - X_{k-1} - u_k^y \geq -M.Q_k^y \qquad k = 3,4,\ldots,N$$

$$-W_k^y + M.Q_k^y \geq 0 \qquad k = 3,4,\ldots,N$$

$$V_k^y, I_k^y, W_k^y \geq 0 \qquad k = 1,2,\ldots N, \forall y = 1,2,\ldots,Y$$

$$O^y \geq 0 \qquad \forall y = 1,2,\ldots,Y$$

$$X_k \geq 0 \qquad k = 1,2,\ldots N - 1$$

$$Q_k^y \in \{0,1\} \qquad k = 3,4,\ldots N, \forall y = 1,2,\ldots,Y$$

The new model considers the physician's lateness, cancellation of outpatient's appointment due to extreme delays, and the ability of patients to cancel their appointments and inform the medical center in a range time before their appointments, whereas these conditions do not exist in the JTY model.

Numerical Example

At this point, the values for the parameters of the models are given. The health center has two daily shifts. The morning shift is from 8 to 12 am, and the afternoon shift from 1 to 5 pm, which are considered 4-hour shifts in this article. This time is indicated by T, which is 240 minutes. The clinic provides each outpatient with a 15-minute unit, which can accommodate up to 16 outpatients in one shift. The probability of no-show outpatients is 20%, which means that this center will give 20 appointments to outpatients in each shift. The physician's overtime rate is 1.5 (β) and outpatients' waiting time rate (α) is 0.1. The "epb" value is also 0.1.

Sensitivity Analysis

In this section, the sensitivity analysis is divided into four categories. It follows an integrated and sequential process. The reasons for the well performance of the new model and its intended contributions are fully identified.

Sensitivity analysis for models' parameters distributions

Two parameters of service time and unpunctuality of outpatients are in probabilistic manner. They have different values in different scenarios. Thus, for optimizing an outpatient appointment scheduling system, it is necessary to use statistical distributions. Initially, it will be required to convert the shift length (240-minutes) to 16 to examine the various statistical distributions (section 2.5.1). However, this conversion describes that we consider for each patient a 15-minute unit. Two tests for statistical distributions have been identified. The first test uses the distributions considered by the JTY model and the second one uses the uniform distribution for the same model as follows:

Test 1: Normal distribution for outpatient unpunctuality parameter and lognormal distribution for the length of service.

$$(21): u_k^y \sim N\left(0, 0.25^2\right),$$

$$(22): \xi_k^y \sim \log normal\left(1, 0.5^2\right).$$

Test 2: Uniform distribution is used for outpatient unpunctuality parameter of outpatients and their length of service.

$$(23): u_k^y \sim U\left(-20/16, 20/16\right),$$

$$(24): \xi_k^y \sim U\left(5/16, 25/16\right).$$

Sensitivity analysis of the amount of cost function changes concerning the physician's lateness parameter

This section examines the amount of cost changes in the four tests according to different values for the physician's lateness distribution. The distributions considered for these four tests are based on the optimally selected distributions obtained from Sections 2.5.1. The number of scenarios considered for the JTY model in these four tests is 30, and the number of patients is 20.

Sensitivity analysis of cancellation due to extreme delays

This contribution is intended for 20 patients. The JTY model and the new model are compared by three critical variables in this study: the physician's overtime, outpatient waiting time and the physician's lateness. The objective function values of both models are obtained. In the meanwhile, the sensitivity analysis was carried out with 30 scenarios. In this section, tests 1 and 2 are done for the JTY model and for the new model, respectively.

Sensitivity analysis for the number of outpatient admissions

In this study, the no-show patient rate is 20%. However, this is not the only factor that let the medical center to accept more outpatients. Some health centers offer outpatients the ability to cancel their appointments in a range of specific time. It is essential to consider this factor for modeling outpatient scheduling systems. On the other hand, the cancellation of outpatients due to extreme delays will be an advantage because the medical center can accept more outpatients. As a result, the sensitivity analysis of these issues is very important.

Results

As stated in Section 2.5, sensitivity analysis is divided into four categories. In Section 2.5.1, the various statistical distributions were considered. The two tests were performed under the same conditions only with the difference in their statistical distributions, which are shown in Chart 1. For brevity, only the physician overtime variable and the cost of the tests have been examined.

As mentioned, the sensitivity analysis of Section 2.5.2 contains four tests, the details of them are shown in Table 1. As a result, the cost values of these tests are examined and shown in Chart 2.

Section 2.5.3 was discussed about the cancellation of outpatients due to extreme delays and has been explained their conditions. The overtime values shown in Chart 3 are intended for 30 scenarios, each of them has 20 outpatients. Also in Chart 4, outpatient waiting times are summarized as a single scenario out of 30 available scenarios. Finally, costs of Section 2.5.3 are shown in Chart 5. For more precision, statistical techniques can be used to examine these two tests. Statistical analysis of Chart 3 and 4 were performed using SPSS software. It should be noted that the data for both tests have a normal distribution, which is determined using the Kolmogorov-Smirnov test of normality. Table 2 shows the results of the normality test. As shown in Table 2, the significant value of both tests are greater than 0.05, so the values of both tests are normal. Consequently, the paired-samples T test can be used to test the assumption of the equality of the two tests, and also Table 2 shows the mean values of the first and the second tests. It is clear that overtime values in test 2 are approximately 20 minutes less than test 1. The significant value of this test was equal to zero, indicating a significant difference between the two tests. The difference in the values of the tests in Chart 4 should also be statistically examined. As with Chart 3, they must first be assumed to be normal. In Table 3 the significant value of test 1 is greater than 0.05, which indicates that it is normal and also the significant value of test 2 is less than 0.05, which means its abnormality.Therefore, the paired-samples T test cannot be used to test for differences in the values. As a result, they should be evaluated using nonparametric tests. The nonparametric test intended to examine Chart 4 is the Mann-Whitney test. The significant value of this test was 0.11, indicating that the two tests were not statistically significant. It is important to note, however, that the average waiting time in test 2 is about 5.27 minutes less than test 1.

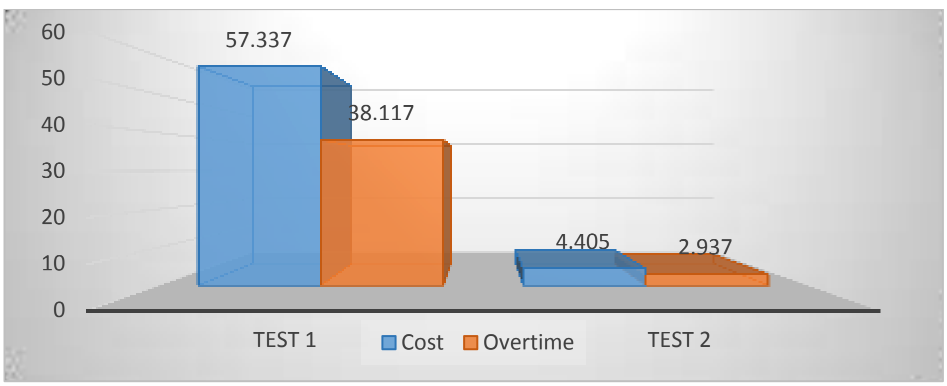

Chart 1. Result of Sensitivity Analysis in Section 2.5.1

Table 1. Details of four tests in Section 2.5.2

Test	Unpunctuality parameter distribution	Service parameter distribution	Physician lateness parameter distribution
1	$u_k^y \sim U(-20, 20)$	$\xi_k^y \sim U(5, 25)$	–
2	$u_k^y \sim U(-20, 20)$	$\xi_k^y \sim U(5, 25)$	$ud_1^y \sim U(0, 15)$
3	$u_k^y \sim U(-20, 20)$	$\xi_k^y \sim U(5, 25)$	$ud_1^y \sim U(0, 30)$
4	$u_k^y \sim U(-20, 20)$	$\xi_k^y \sim U(5, 25)$	$ud_1^y \sim U(0, 45)$

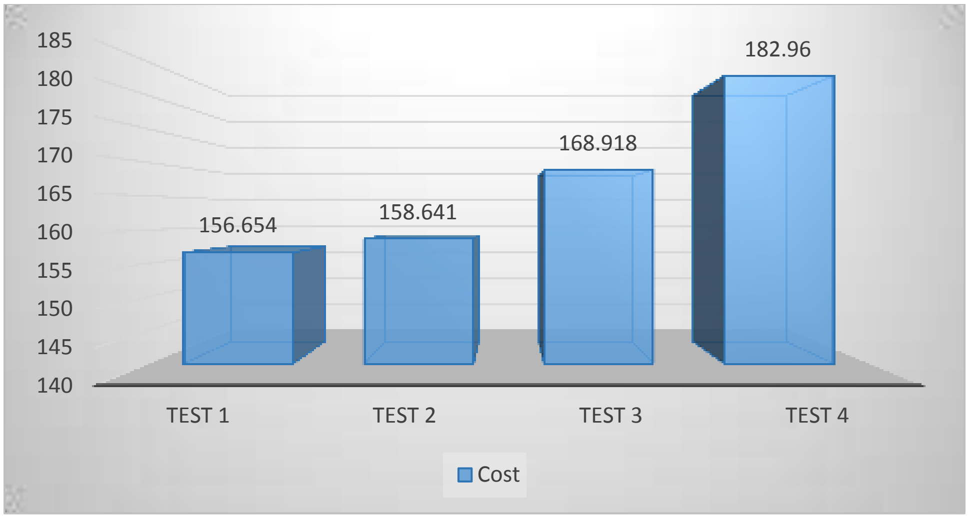

Chart 2. Cost sensitivity analysis result for different values of the physician's lateness distribution in Section 2.5.2

Table 2. One-Sample Kolmogorov-Smirnov Test for Section 2.5.3

		Overtime.Test1	Overtime.Test2
Number of scenarios		30	30
Normal Parameters	Mean	76.08043	56.28250
	Std. Deviation	22.942611	25.398002
Asymp. Sig. (2-tailed)		.200	.200

Table 3. One-Sample Kolmogorov-Smirnov Test for Section 2.5.3

		Waitingtime.Test1	Waitingtime.Test2
Number of outpatient		20	20
Normal Parameters	Mean	17.16435	11.88980
	Std. Deviation	11.599755	13.967615
Asymp. Sig. (2-tailed)		.200	.002

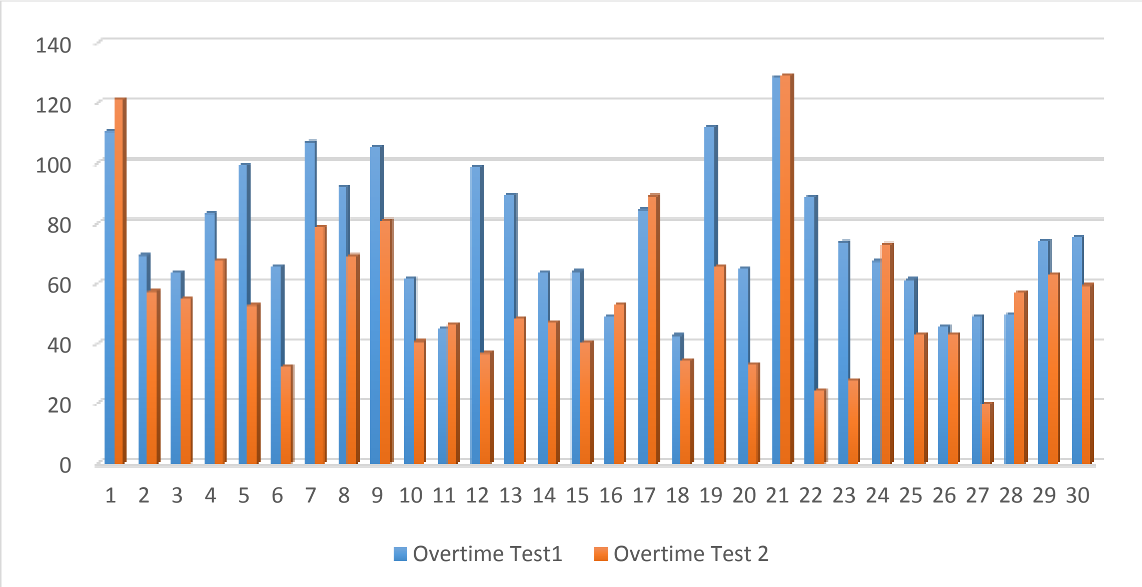

Chart 3. overtime sensitivity analysis results in 2.5.3 Section

The sensitivity analysis of Section 2.5.4 is complementary to its preceding sections. As described in Section 2.5.4, the sensitivity analysis is concerned with the number of outpatients admitted to the appointment system. There are three factors that make it possible to increase the number of outpatients receiving admission. Outpatient cancellation due to extreme delays can cause some outpatients to be canceled. However, the maximum number of cancellations will not reach 4 people based on the parameters considered for the scenarios. Also, and the no-show outpatients, causes the number of outpatients who have been assigned to no longer be present, and the number of outpatients may be less than it. Finally, in the new model, it was observed that the physician's idleness increased. All of these three factors led to this sensitivity analysis. The results of this sensitivity analysis are shown in charts 6 and 7 which are based on the four tests (respectively): cost of the JTY model for 20 outpatients, cost of the new model for 20 outpatients, cost of the new model for 21 outpatients, and cost of the new model for 22 outpatients.

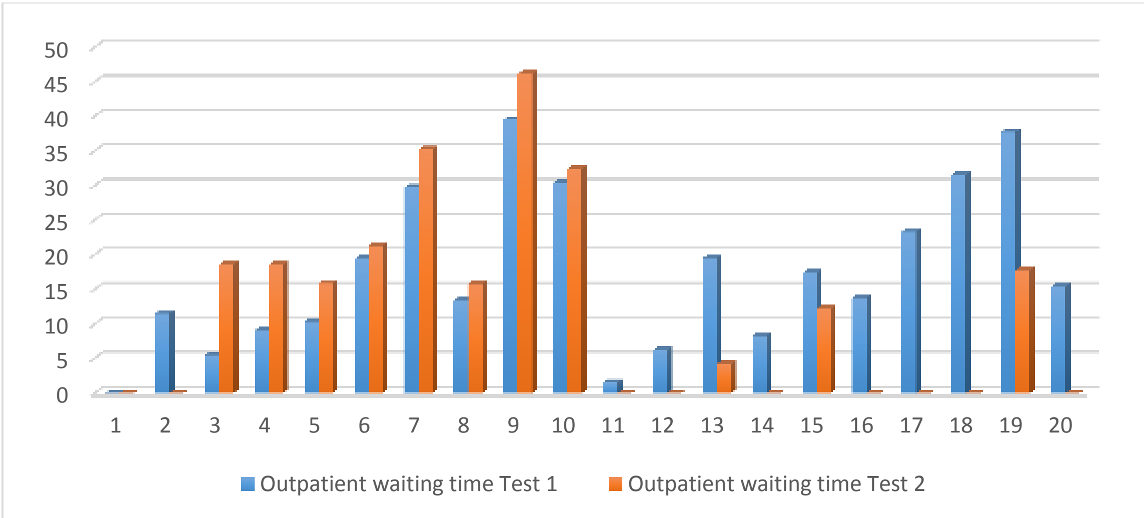

Chart 4. Outpatient waiting time sensitivity analysis results in Section 2.5.3

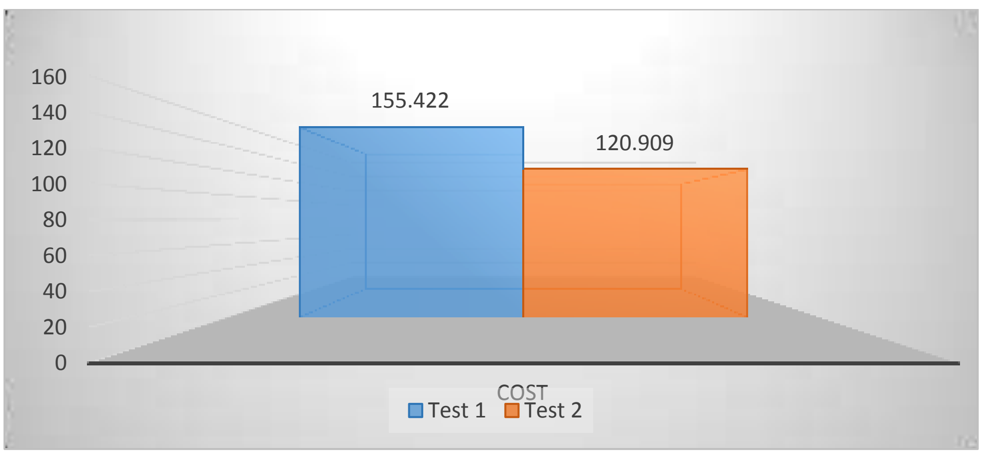

Chart 5. Cost sensitivity analysis results in Section 2.5.3

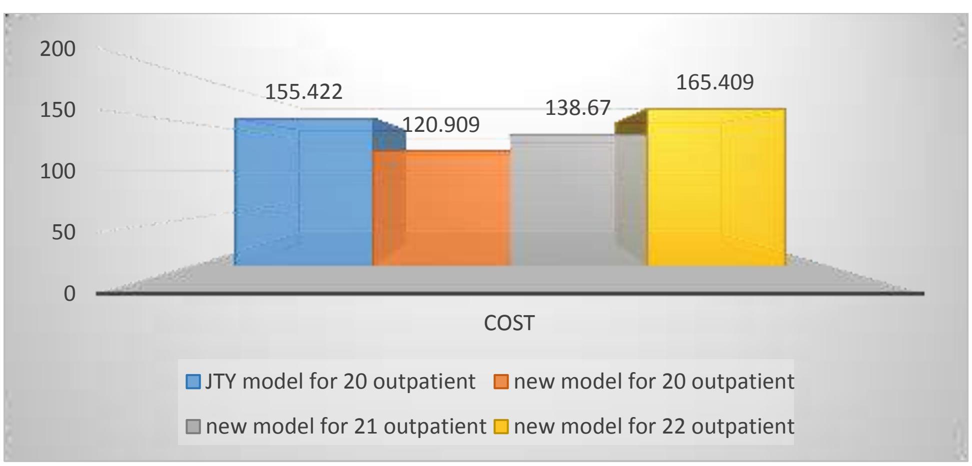

Chart 6. Sensitivity analysis for the number of outpatient admissions results in Section 2.5.4

The statistical distribution for the physician's lateness parameter in Chart 7 is $ud_1^y \sim U(0,30)$.

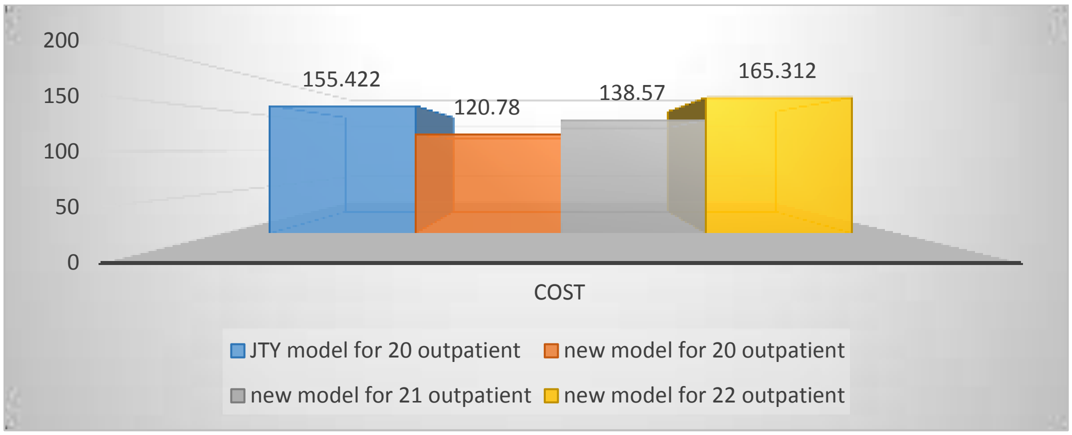

Chart 7. Sensitivity analysis for the number of outpatient admissions results with considering the physician's lateness in Section 2.5.4

According to Chart 7, the new model is optimal if 21 patients were admitted. Therefore, the results of this model will be presented for 21 patients. To summarize, only 2 scenarios out of 30 are shown. Table 4 shows the values of the variable X_k.

Table 4. Values of the variable X_k

Number	Time
2	10.57
3	11.49
4	9.5
5	14.67
6	18.34
7	5.35
8	28.3
10	16.8
11	22.4
12	12.58
13	17.4
14	18.8
15	19.3
16	6.69
17	10.22
18	31.2
20	5.22

The two scenarios are called Scenario A and Scenario B, respectively. In scenario A, the fourth and tenth appointments of patients were canceled due to extreme delay. In Scenario B, the 20th patient appointment is also canceled. Table 5 presents the values of V_k^y and W_k^y for these two scenarios.

The idle times of the physician in Scenario A for the third and fifth patients were 11.49 and 5.12 minutes, respectively. Also, the idle time of the physician in Scenario B for nineteenth patients was 3.65 minutes. The idle times in these two scenarios were zero for the other patients. The overtime in scenarios A and B were 67 and 42 minutes, respectively.

Table 5. The values of V_k^y and W_k^y

Number	Scenario A		Scenario B	
	V_k^y	W_k^y	V_k^y	W_k^y
1	28.78	14.44	0.6	0.6
2	0	0	0	0
3	0	0	34.63	23.71
4	0	0	30.2	22.47
5	0	0	34.31	22.8
6	11.49	9.64	32.35	23.01
7	17.99	15.08	16.57	16.57
8	41.17	26.46	27.23	27.23
9	0	0	44.28	31.6
10	0	0	26	26
11	10.44	7.3	32.88	28.02
12	0	0	37.5	27.72
13	15.73	9.85	36.54	24.87
14	5.98	5.98	35.22	24.88
15	28.05	14.6	42.45	29.3
16	15.5	2.9	1.9	1.9
17	13.39	11.12	30.63	25.33
18	29.95	15.78	19.79	19.79
19	4.33	0	0	0
20	27.68	9.92	0	0
21	34.38	22.79	17.19	17.19

Discussion

● As can be seen in Chart 1, uniform statistical distributions for unpunctuality outpatient parameters and length of service, have lower overtime and lower cost. Therefore, the second test is superior to the first one and is optimal. As a result, uniform statistical distribution is more consistent with the model. Therefore, for the probabilistic parameter of physician's lateness in Section 2.5.2, the uniform distribution is considered.

● The results of Chart 2 show that the higher the statistical distribution of the physician's lateness parameter, the greater is the cost of the outpatient appointment system. As a result, the physician's lateness parameter is a significant factor in its application for modeling scheduling systems, so it cannot be easily ignored.

● As can be seen in Chart 3, the contributions in the new model has reduced the amount of overtime. From Chart 4, although the difference was not statistically significant, the mean of the second test was lower than the first one.

● In the new model, the physician's idle time is higher than the JTY model. In the JTY model the physician's idle time is zero for all patients, but for the scenarios considered, the physician's idle time in the new model for eleventh, sixteenth, and eighteen outpatients are 1.861, 1.623, and 3.596 minutes, respectively. Finally, the costs obtained in the sensitivity analysis of Section 2.5.3 are presented in Chart 5, which show that the new model is less costly than the JTY model.

● As shown in Chart 6, costs increase with the increase in the number of outpatients, and in this case, the costs of the new model are lower than the ones of the JTY model. The results of Chart 6 show that the optimal test is in the condition that the medical center accepts 21 patients according to the new model. Although, there are no physician's lateness parameters in Chart 6, but Chart 7 considers them. As it is evident, the physician's lateness is a parameter that increases costs. However, it is more costly when the model lacks this parameter and this indicates that the new model is better than the JTY model.

Conclusion

Modeling in the field of outpatient appointment systems is significant for optimizing medical centers and increasing outpatient satisfaction. This paper described the JTY model. Then, by considering new items a new model is formulated. Different tests were also performed for sensitivity analysis and comparison of these two models. The obtained values were evaluated and analyzed. The results of these studies showed that the new model as a stochastic mixed-integer program is a better model in terms of the new items.

The proposed model in this study can be considered for more than one physician in various specialties. The more scenarios considered for the model, the better the results of the model will be. Still due to the increasing complexity of the model, it will be needed to be solved by methods such as Benders' decomposition algorithm, L-Shape algorithm, Lagrangean relaxation algorithm, and Dantzig-Wolf's decomposition algorithm.

Conflict of interests

None.

Authors' contributions

The authors are the same

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