
An Analytical Comparison of the Patient-to-Doctor Policy and the Doctor-to-Patient Policy in the Outpatient Clinic

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Abstract Outpatient clinics traditionally organize processes such that the doctor remains in a consultation room, while patients visit for consultation, we call this the Patient-to-Doctor policy. A different approach is the Doctor-to-Patient policy, whereby the doctor travels between multiple consultation rooms, in which patients prepare for their consultation. In the latter approach, the doctor saves time by consulting fully prepared patients. We compare the two policies via a queueing theoretic and a discrete-event simulation approach. We analytically show that the Doctor-to-Patient policy is superior to the Patient-to-Doctor policy under the condition that the doctor's travel time between rooms is lower than the patient's preparation time. Simulation results indicate that the same applies when the average travel time is lower than the average preparation time. In addition, to calculate the required number of consultation rooms in the Doctor-to-Patient policy, we provide an expression for the fraction of consultations that are in immediate succession; or, in other words, the fraction of time the next patient is prepared and ready, immediately after a doctor finishes a consultation. We apply our methods for a range of distributions and parameters and to a case study in a medium-sized general hospital that inspired this research.

Keywords Outpatient clinic · health care · queueing theory · discrete-event simulation

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1 Introduction

Demand for outpatient care is growing as a result of increasingly effective ambulatory care treatments and the overall growth of health care demand. Hence, managers of outpatient clinics are becoming increasingly aware of the importance of the efficient use of scarce resources, particularly doctor's time and facility space [8].

In many hospitals, outpatient clinics are organized such that doctors remain in one consultation room, while patients visit for individual consultation. In this classic design, each doctor occupies one consultation room, which often doubles as the doctor's office [24]. Patients wait in the waiting room until the doctor is available, and then enter the doctor's office for the consultation. We label this classic design Patient-to-Doctor policy (PtD-policy).

In a different approach, patients prepare themselves in separate, individual consultation rooms. Each patient is then visited by the doctor, who travels from room to room. We label this approach as Doctor-to-Patient policy (DtP-policy). The DtP-policy offers a potential decrease in total service time, given that doctors do not have to be present for patient preparation activities that require a consultation room, but do not require a doctor. We characterize these activities as pre-consultation (e.g., travelling to the room, undressing, blood pressure measures) and post-consultation (e.g., dressing, making appointments, leaving the room). Nurses or assistants may be involved in these activities. In the DtP-policy, the doctor experiences travel time between each consultation, whilst traveling from room to room. Figure 1 illustrates the PtD-policy and the DtP-policy with two rooms.

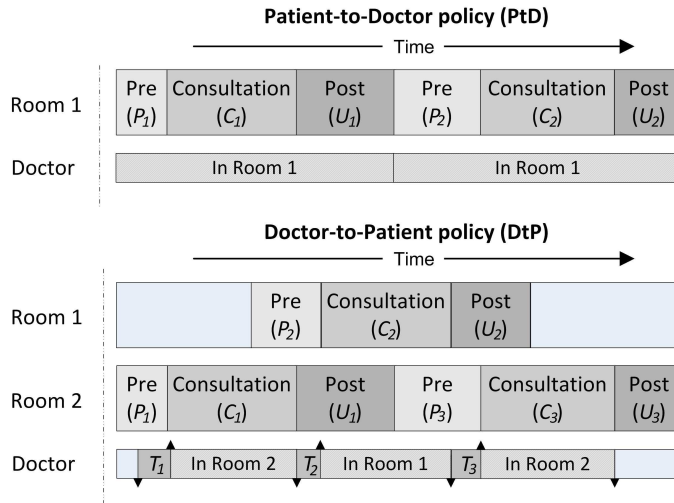


Fig. 1 An illustration of the PtD-policy and the DtP-policy with two rooms. Pre-consultation, consultation and post-consultation for patient n is indicated by P_n , C_n and U_n respectively. T_n indicates the travel time of the doctor to patient n

In queueing terminology, the PtD-policy resembles a $G/G/1$ queueing model, under the assumption that patients are seen on a first-come, first-served basis (FCFS). The DtP-policy seems to resemble a polling system [19, 23], where the server travels between multiple customer queues. However, as the outpatient clinic has a single queue of patients only, this analogy can not be applied to evaluate the DtP-policy. The queueing model that most closely resembles the DtP-policy is a Production Authorization Card system (PAC-system). In a PAC-system, the number of jobs (patients) at a station (the doctor) is bounded by the number of PACs (rooms). Therefore, the departure of a job (patient exits) initiates demand for new jobs (a patient enters the empty room). The PAC-system, and thus the DtP-policy, is a typical ‘pull’ system, used in popular management philosophies such as Just-In-Time and Kanban. The PtD-policy is a ‘push’ system, whereby patients arrive in a buffer (the waiting room) and are pushed through the system. For results in queueing theory on push and pull systems, see [3, 17]. The exact and approximative solution approaches for PAC-systems are based on steady state queueing results [5]. Since appointment schedules have a finite number of customers, and thus do not reach steady state [6, 13, 20], these solution approaches are inappropriate to analyze the DtP-policy and the PtD-policy.

There is a significant body of literature on resource planning in outpatient clinics, particularly related to outpatient scheduling. For a comprehensive review of the literature on outpatient scheduling, see [6]. The design and capacity dimensioning of outpatient clinics has received less attention in the literature. Different process set-ups for an emergency department are compared with a Multi-Class Open Queueing Network (MC-OQN) in [15]. The authors conclude that parallel processing of, for example, treatment and diagnostic tests, rather than serial processing, results in a shorter patient sojourn time under certain conditions. Other examples of successful process redesigns in outpatient clinics are [7, 25]. Simulation is used to find the required number of examination rooms in an outpatient clinic [8], an obstetrics outpatient center [14], a radiology department [16], an emergency department [1, 10] and a family practice [21, 22]. A combination of simulation and function estimation is used to design a transfusion center [9]. All described papers use simulation to find the required number of rooms for a specific setting. In this paper, we develop analytical models of a generic outpatient clinic to compare the PtD-policy with the DtP-policy, and to determine the required number of rooms in the DtP-policy.

The performance measures we consider are doctor utilization, access time, and patient waiting time. Doctor utilization is the fraction of time the doctor is actually consulting a patient. Access time is the time between the request for an appointment and the realization of the appointment. Patient waiting time is the time between the scheduled starting time of the appointment and the actual starting time of the appointment. Increased doctor utilization leads to decreased access time, but also to increased patient waiting time, given that more patients are scheduled per time unit. Managers of outpatient clinics strive for high doctor utilization and low access times, even at the cost of some

patient waiting time [4]. This may be explained by three factors: doctors are considered expensive resources, service level agreements on access times may exist and low access times may attract more patients.

This paper is organized as follows. Section 2 introduces the model and presents expressions for the recursion of the time that the doctor finishes a consultation in both the PtD-policy and the DtP-policy. Section 3 compares these recursions analytically, and introduces an expression for the fraction of consultations that are in immediate succession, to calculate the required number of consultation rooms in the DtP-policy. Section 4 presents the results for a range of distributions and parameters, and a case study at a medium-size hospital. Section 5 discusses main conclusions.

2 Model

In Sections 2.1 and 2.2, we develop expressions for the time the doctor finishes the consultation of the n -th patient in the PtD-policy (F_n) and the DtP-policy (F'_n). These expressions are used in Section 3.1, to compare the PtD-policy and the DtP-policy. We first introduce notation and assumptions that apply to both policies.

Assume that at time zero the doctor is free. Patients arrive according to a stochastic process at time points $\{A_n, n = 1, 2, \dots, N\}$, thus the first patient arrives at time A_1 . The n -th patient leaves the system after finishing pre-consultation (P_n), consultation with the doctor (C_n) and post-consultation (U_n), where P_n, C_n, U_n are random variables with $P_n, C_n, U_n \geq 0$, for $n = 1, 2, \dots, N$. The n -th patient leaves at time $D_n = F_n + U_n$ in the PtD-policy, and at time $D'_n = F'_n + U_n$ in the DtP-policy. Let R be the number of rooms and T_n the random variable for the doctor's travel time to the n -th patient. We assume that $T_n, n = 1, 2, \dots, N$, is an independent and identically distributed (i.i.d.) sequence of random variables, thus not connected to the sequence with which the doctor visits the rooms, and that the travel time of the doctor (T_n) is not longer than the travel time of the patient (included in P_n). We base the latter assumption on our experience that consultation rooms are located adjacently and the waiting room is at a further distance.

Assumption 1 $T_n \leq P_n$, for $n = 1, 2, \dots, N$.

Throughout this paper, inequalities in expressions and equations for random variables are with probability one, i.e., $T_n \leq P_n \Leftrightarrow Pr(T_n \leq P_n) = 1$. The following two assumptions imply that patients enter rooms and are consulted by the doctor in the sequence they arrive.

Assumption 2 *Patients enter rooms on an FCFS basis. Hence, when a room is empty, the patient who has waited the longest in the queue is admitted.*

Assumption 3 *The doctor consults patients on an FCFS basis, thus in the sequence in which the patients enter rooms.*

The following assumption deals with the doctor's travel in the DtP-policy after finishing consultation with a patient.

Assumption 4 *When the doctor finishes consultation with the $(n-1)$ -th patient, and the n -th patient has not entered a room yet, the doctor travels to an empty room when one becomes available, and waits there for the n -th patient.*

Under Assumption 4, the doctor either knows which room to go to after finishing consultation of a patient, or the doctor waits until a patient leaves and a room becomes available.

2.1 Recursion of the time the doctor finishes a consultation in the PtD-policy

We obtain the following expression for the recursion of the time that the doctor finishes the consultation of a patient in the PtD-policy.

Lemma 5 $F_n = \max\{A_n, F_{n-1} + U_{n-1}\} + P_n + C_n$, where $n = 1, 2, \dots, N$ and $F_0 = 0$.

Proof

Consider the recursion of the departure process. We distinguish two cases:

- i.* When $A_n \geq D_{n-1}$, the n -th patient comes in after the $(n-1)$ -th patient has left, thus the doctor is available immediately upon arrival of the n -th patient at A_n . Hence, $D_n = A_n + P_n + C_n + U_n$.
- ii.* When $A_n < D_{n-1}$, the n -th patient comes in while the doctor is occupied. The n -th patient can start pre-consultation upon departure of the $(n-1)$ -th patient. Hence, $D_n = D_{n-1} + P_n + C_n + U_n$.

Combining (i) and (ii) obtains

$$D_n = \max\{A_n, D_{n-1}\} + P_n + C_n + U_n. \quad (1)$$

Since $D_n = F_n + U_n$, we have proven the lemma. \square

2.2 Recursion of the time the doctor finishes a consultation in the DtP-policy

Since the processes in the DtP-policy and the PtD-policy are identical when $R = 1$, we focus on $R > 1$ in the DtP-policy.

The exiting time for patients may not be in the same order as the arrivals, because it is possible for the $(n+1)$ -th patient to exit before the (n) -th patient (due to the randomness in U_n). To accommodate this, we define the $s(n)$ -th patient as the patient who is succeeded by the n -th patient in a room. Thus

when the $s(n)$ -th patient exits a room, the n -th patient enters that room. We obtain the following expression for the recursion of the time that the doctor finishes the consultation of a patient in the DtP-policy.

$$\mathbf{Lemma\ 6} \quad F'_n = \begin{cases} \max\{A_n + P_n, F'_{n-1} + T_n\} + C_n & , \text{ if } n \leq R \\ \max\{\max\{F'_{s(n)} + U_{s(n)}, A_n\} + P_n, \\ \max\{F'_{s(n)} + U_{s(n)}, F'_{n-1}\} + T_n\} + C_n & , \text{ if } n > R \end{cases},$$

where $n = 1, 2, \dots, N$ and $F'_0 = 0$.

Proof

The recursion of the finishing time for the doctor is explained by examining the time both the patient and the doctor are ready for consultation. The n -th patient is available for consultation after finishing pre-consultation. The doctor is available for the n -th patient, after the consultation of the $(n-1)$ -th patient plus the travel to the n -th patient. We distinguish two cases:

- i.* When $n \leq R$, the number of customers in the system is smaller than the number of rooms. Hence, the n -th patient enters a room immediately upon arrival and is ready for consultation after pre-consultation ($A_n + P_n$). The doctor consults the patient after finishing consultation of the $(n-1)$ -th patient and the travel time ($F'_{n-1} + T_n$). The moment consultation can start if $n \leq R$ is thus: $\max\{A_n + P_n, F'_{n-1} + T_n\}$.
- ii.* When $n > R$, the n -th patient may have to wait for the exit of the $s(n)$ -th patient ($F'_{s(n)} + U_{s(n)}$) before entering a room, or the patient can enter a room immediately upon arrival (A_n), if a room is available. After entering a room, pre-consultation has to be finished before consultation can start. Hence, the patient is ready for consultation at $\max\{F'_{s(n)} + U_{s(n)}, A_n\} + P_n$. The doctor is ready for consultation after traveling to the room (T_n). The doctor can start traveling after the consultation of the $(n-1)$ -th patient (F'_{n-1}), and, due to Assumption 4, the $s(n)$ -th patient must have exited ($F'_{s(n)} + U_{s(n)}$). Therefore, the doctor is available for the consultation of the n -th patient at $\max\{F'_{s(n)} + U_{s(n)}, F'_{n-1}\} + T_n$. The moment consultation can start if $n > R$ is thus $\max\{\max\{F'_{s(n)} + U_{s(n)}, A_n\} + P_n, \max\{F'_{s(n)} + U_{s(n)}, F'_{n-1}\} + T_n\}$.

We combine (i) and (ii) to obtain Lemma 6. \square

3 Analytical performance evaluation

We use Lemmas 5 and 6 obtained in Section 2 to compare the DtP-policy with the PtD-policy in Section 3.1. In Section 3.2 we develop an expression for the fraction of consultations that are in immediate succession to calculate the required number of rooms in the DtP-policy.

3.1 Analytical comparison of the recursion of the finishing time for the doctor under both policies

In this section, we show that the time that the doctor finishes the consultation of a patient in the DtP-policy is not later than the time the doctor finishes consultation with that patient in the PtD-policy, under Assumptions 1, 2, 3 and 4, i.e.,

Theorem 7 $F'_n \leq F_n$, for $n = 1, 2, \dots, N$.

Proof

We prove this theorem by induction. Clearly $F'_1 \leq F_1$, since in an initial (empty) system, the process is identical, because we have Assumption 1. The induction hypothesis is $F'_j \leq F_j$, for $j = 1, 2, \dots, n-1$. It remains to prove that $F'_n \leq F_n$.

Observe from Assumptions 2 and 3 that $F_{n-1} \leq F_n$ and $F'_{n-1} \leq F'_n$. Additionally, the $s(n)$ -th patient is the patient that leaves a room before the n -th patient can enter that room. Therefore, it is certain that the $s(n)$ -th patient has entered a room before the n -th patient, so that

$$F'_{s(n)} + U_{s(n)} \leq F'_{n-1} + U_{n-1}, \text{ for } n = 1, 2, \dots, N. \quad (2)$$

It is sufficient to consider the case $n > R$, since for $n \leq R$ by definition we have $F'_{s(n)} + U_{s(n)} = 0$.

For the case $A_n \leq F'_{s(n)} + U_{s(n)}$, we obtain:

$$\begin{aligned} F'_n &= \max\{F'_{s(n)} + U_{s(n)} + P_n, \\ &\quad \max\{F'_{s(n)} + U_{s(n)}, F'_{n-1}\} + T_n\} + C_n && \text{(Lemma 6, } n > R) \\ &\leq \max\{F'_{n-1} + U_{n-1} + P_n, \\ &\quad \max\{F'_{n-1} + U_{n-1}, F'_{n-1}\} + T_n\} + C_n && \text{(Equation (2))} \\ &= F'_{n-1} + U_{n-1} + \max\{P_n, T_n\} + C_n \\ &\leq F_{n-1} + U_{n-1} + \max\{P_n, T_n\} + C_n && \text{(Induction hypothesis)} \\ &\leq F_{n-1} + U_{n-1} + P_n + C_n && \text{(Assumption 1)} \\ &\leq \max\{A_n, F_{n-1} + U_{n-1}\} + P_n + C_n = F_n && \text{(Lemma 5)} \end{aligned}$$

For the case $A_n \geq F'_{s(n)} + U_{s(n)}$, we obtain:

$$\begin{aligned} F'_n &= \max\{A_n + P_n, \max\{F'_{s(n)} + U_{s(n)}, F'_{n-1}\} + T_n\} + C_n \text{ (Lemma 6, } n > R) \\ &\leq \max\{A_n + P_n, \max\{A_n, F'_{n-1}\} + T_n\} + C_n \\ &= \max\{A_n + \max\{P_n, T_n\}, F'_{n-1} + T_n\} + C_n \\ &\leq \max\{A_n + \max\{P_n, T_n\}, F_{n-1} + T_n\} + C_n && \text{(Induction hypothesis)} \\ &\leq \max\{A_n + P_n, F_{n-1} + P_n\} + C_n && \text{(Assumption 1)} \\ &\leq \max\{A_n, F_{n-1} + U_{n-1}\} + P_n + C_n = F_n && \text{(Lemma 5)} \end{aligned}$$

From the above, it follows that if $F'_j \leq F_j$, for $j = 1, 2, \dots, n-1$, then $F'_n \leq F_n$. This proves the theorem. \square

Since $F'_n \leq F_n$, for $n = 1, 2, \dots, N$, this also means $D'_n \leq D_n$, for $n = 1, 2, \dots, N$. Therefore, the departure of the n -th patient never occurs later in the DtP-policy than the departure of that same patient in the PtD-policy.

Remark 8 *Under our FCFS assumptions, Assumptions 2 and 3, the modeled DtP-policy performs worse than a real-life DtP-policy, where the doctor may consult patients according to a dynamic sequence. The FCFS ordering may result in a waste of doctor capacity, since the doctor may be waiting for the n -th patient to finish pre-consultation, while the $(n+1)$ -th patient is already finished with pre-consultation. Additionally, Assumption 4 also causes waste of capacity, since the doctor waits until knowing which room to travel to next. This suggests that the ordering of the DtP-policy and the PtD-policy also holds when Assumptions 2, 3 and 4 are relaxed.*

Remark 9 *When Assumption 1 is replaced by the weaker assumption $Pr(T_n \leq s) \geq Pr(P_n \leq s)$, for $n = 1, 2, \dots, N$, we can show that $Pr(F'_n \leq t) \geq Pr(F_n \leq t)$, for $n = 1, 2, \dots, N$, which implies that $\mathbb{E}F' \leq \mathbb{E}F$.*

3.2 Analytical expression to calculate the required number of rooms

To minimize access time of patients, we aim to minimize idle time experienced by the doctor. To this end, the doctor's wait for the next available patient should be minimized [12], or in other words, the *fraction of consultations that take place in immediate succession* should be maximized. After leaving a room, the doctor should return to this room after the next patient has finished pre-consultation. During the time that the doctor is away from a specific room ($U_{s(n)} + P_n$), the doctor performs $R - 1$ consultations in the other rooms and R travels (including the travel to the n -th patient). Hence, we obtain the following expression, where the number of rooms (R) is chosen such that the fraction of consultations in immediate succession is larger than α , where $0 \leq \alpha \leq 1$.

$$Pr\left(\sum_{k=n-R}^{n-1} C_k + \sum_{k=n-R}^n T_k \geq U_{s(n)} + P_n\right) \geq \alpha. \quad (3)$$

Examples

We evaluate Equation (3) for Gamma and Normal distributed service times. The average duration of a process is given by μ_i and its variance is given by σ_i^2 , where $i \in \{P, C, U, T\}$.

The Gamma distribution is a frequently reported distribution for outpatient clinic consultation times [6]. Let the pre-consultation, the post-consultation, and the travel times be deterministic, and the consultation times be i.i.d. Gamma distributed. The convolution of v i.i.d. Gamma distributed variables with parameters (k, θ) is again a Gamma distribution with parameters $(v \cdot k, \theta)$. Hence, the number of rooms, R , is obtained from

$$\int_{U+P-R \cdot T}^{\infty} x^{(R-1) \cdot (k-1)} \frac{e^{-\frac{x}{\theta}}}{\theta^{(R-1) \cdot k} \cdot \Gamma(R \cdot k)} dx \geq \alpha, \quad (4)$$

where $\theta = \frac{\sigma_C^2}{\mu_C}$ and $k = \frac{\mu_C}{\theta}$ are parameters of the Gamma distribution and $\Gamma(a)$ is the standard Gamma function with parameter a .

When all service processes are i.i.d. Normal distributed, its convolution results in a Normal distribution with parameters (μ, σ) . Hence, the number of rooms, R , is obtained from

$$\int_0^{\infty} \frac{1}{\sqrt{2\pi}\sigma} e^{-(x-\mu)^2/2\sigma^2} dx \geq \alpha, \quad (5)$$

where $\mu = (R-1) \cdot \mu_C + R \cdot \mu_T - \mu_U - \mu_P$ and $\sigma^2 = (R-1) \cdot \sigma_C^2 + R \cdot \sigma_T^2 + \sigma_P^2 + \sigma_U^2$.

4 Results

Sections 4.1 and 4.2 describe the comparison of the two policies and the calculation of the required number of rooms. Section 4.3 describes the application of our methods at a pediatric outpatient clinic.

4.1 Comparison of the PtD-policy and the DtP-policy

In Theorem 7, we showed that the doctor finishes consultation with a patient earlier in the DtP-policy than in the PtD-policy under Assumptions 1, 2, 3 and 4. Hence, more patients can be consulted per time unit in the DtP-policy. In Remark 8, we indicated that the ordering of the DtP-policy and the PtD-policy may remain the same when Assumptions 2, 3 and 4 are relaxed. Below, we use discrete-event simulation to study the ordering when Assumption 1 is relaxed.

The discrete-event simulation is a model of an outpatient clinic, where a consultation session lasts eight hours per day and patients arrive at the time they are scheduled. The Bailey-Welch rule [2] is used for the patient schedule. The rule states that when blocks of the size of the expected consultation time are used to schedule the patients, the last block is deleted and the first block holds two patients. We assume a coefficient of variation ($CV = \frac{\mu}{\sigma}$) of 0.6, which is within the range of 0.35 to 0.85 reported in the literature [6]. The length of each simulation run is five business days. With the replication/deletion approach [18], we find that 200 replications appear to be sufficient for a confidence level of 99.9% with a relative error of 0.1% with respect to the number of consultations per week.

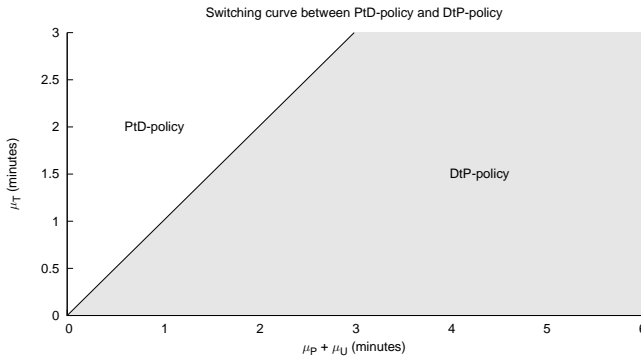


Fig. 2 The switching curve between the DtP-policy and the PtD-policy, where all processes are Gamma distributed with $CV = 0.6$. A policy is superior to the other policy, when average doctor utilization is significantly higher. The number of rooms is chosen with Equation (3), with $\alpha = 0.90$

Figure 2 shows the switching curve when all processes are Gamma distributed. The switching curve from the PtD-policy to the DtP-policy depends on the ratio of doctor travel time to pre-consultation time and post-consultation time, and is insensitive to changes in the average consultation time and the CV . Also, the ratio pre-consultation to post-consultation has only negligible impact on the choice for a policy; it is their sum that influences the superiority of a policy.

When ρ is varied ($\rho = \lambda E[C]$, where λ is the number of patients scheduled per time unit, and $E[C]$ is the expected consultation time), the switching curve for the DtP-policy is identical to the curve in Figure 2 for $\rho \geq 0.7$. For $\rho < 0.7$, the DtP-policy performs better at even higher average travel times, but the potential benefit of the DtP-policy is relatively low, as can be seen in Figure 3.

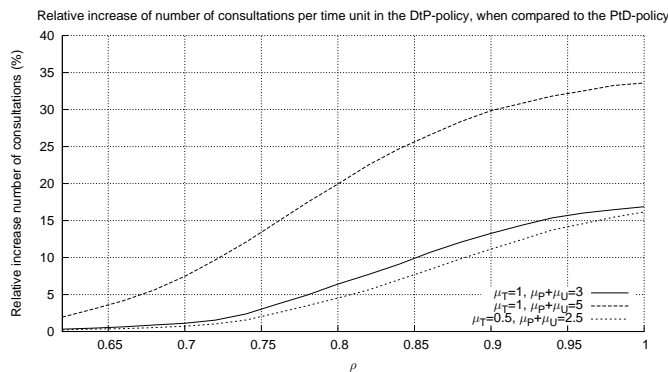


Fig. 3 The effect of varying ρ on the relative increase of the number of consultations per time unit in the DtP-policy, when compared to the PtD-policy. All processes are Gamma distributed with $CV = 0.6$, $\mu_C = 10$, and $R = 2$

4.2 Evaluation of the required number of rooms

The fraction of consultations that are in immediate succession (P_{succ} in Table 4), left-hand side in Equation (3), is evaluated numerically with Monte Carlo simulation for the Gamma, Lognormal and Exponential distribution. For the Normal distribution, we use Equation 5. To compare the fraction with a performance measure, such as doctor utilization ($Util.$ in Table 4), we use the discrete-event simulation introduced in Section 4.1. Table 4 presents both the fraction results and the doctor utilization for a given number of rooms, and it shows the effect of choosing a certain α . For example, when $\alpha = 0.90$, four rooms are required when $\mu_P = \mu_U = 9$ and all processes Lognormal distributed. In that case, the doctor utilization found with the simulation is 90.4%. The results in Table 4 show that doctor utilization increases with the fraction of consultations that are in immediate succession.

Table 4 The results for the fraction of consultations that are in immediate succession, where $\mu_T = 1$ and $CV = 0.6$ for the Gamma, Lognormal and Normal distributions, and $CV = 1$ for the Exponential distribution. The half-length of the 99.9% confidence interval for the doctor utilization is between 0.011% and 0.096%

R	(μ_P, μ_C, μ_U)	Gamma		Lognormal		Normal		Exponential	
		P_{succ}	$Util.$	P_{succ}	$Util.$	P_{succ}	$Util.$	P_{succ}	$Util.$
2	(3,15,3)	0.920	91.2%	0.946	91.4%	0.879	91.1%	0.781	86.6%
3	(3,15,3)	0.998	91.6%	0.996	91.6%	0.981	91.8%	0.960	87.6%
4	(3,15,3)	1.000	91.6%	0.997	91.6%	0.997	91.8%	0.993	87.7%
2	(3,15,6)	0.800	89.8%	0.823	90.3%	0.791	89.6%	0.674	84.6%
3	(3,15,6)	0.985	91.5%	0.979	91.6%	0.963	91.7%	0.909	87.4%
4	(3,15,6)	0.999	91.6%	0.988	91.6%	0.993	91.8%	0.976	87.7%
2	(3,15,9)	0.675	87.0%	0.687	87.6%	0.680	87.0%	0.591	81.9%
3	(3,15,9)	0.953	91.4%	0.945	91.5%	0.933	91.5%	0.852	87.0%
4	(3,15,9)	0.995	91.6%	0.973	91.6%	0.987	91.8%	0.949	87.6%
2	(6,15,3)	0.800	89.4%	0.823	89.7%	0.791	89.1%	0.674	84.1%
3	(6,15,3)	0.985	91.0%	0.979	91.0%	0.963	91.2%	0.909	86.8%
4	(6,15,3)	0.999	91.0%	0.988	91.0%	0.993	91.3%	0.976	87.0%
2	(6,15,6)	0.671	86.8%	0.684	87.3%	0.685	86.6%	0.580	81.5%
3	(6,15,6)	0.958	90.8%	0.952	90.9%	0.937	91.0%	0.853	86.4%
4	(6,15,6)	0.997	91.0%	0.978	91.0%	0.988	91.2%	0.953	87.0%
2	(6,15,9)	0.551	83.0%	0.550	83.5%	0.571	83.0%	0.509	78.2%
3	(6,15,9)	0.911	90.5%	0.903	90.6%	0.896	90.6%	0.794	85.6%
4	(6,15,9)	0.989	90.9%	0.961	91.0%	0.978	91.2%	0.921	86.9%
2	(9,15,3)	0.675	86.1%	0.687	86.6%	0.680	85.9%	0.591	81.0%
3	(9,15,3)	0.953	90.2%	0.945	90.3%	0.933	90.4%	0.852	85.8%
4	(9,15,3)	0.995	90.3%	0.973	90.4%	0.987	90.7%	0.949	86.4%
2	(9,15,6)	0.551	82.6%	0.550	83.1%	0.571	82.5%	0.509	77.8%
3	(9,15,6)	0.911	89.9%	0.903	90.0%	0.896	89.9%	0.794	85.0%
4	(9,15,6)	0.989	90.3%	0.961	90.4%	0.978	90.6%	0.921	86.3%
2	(9,15,9)	0.449	78.3%	0.434	78.7%	0.466	78.4%	0.446	74.3%
3	(9,15,9)	0.853	89.2%	0.844	89.4%	0.843	89.2%	0.739	84.0%
4	(9,15,9)	0.975	90.3%	0.944	90.4%	0.963	90.6%	0.887	86.1%
5	(9,15,9)	0.996	90.4%	0.960	90.4%	0.992	90.7%	0.953	86.4%

The stochastic nature of the consultation process should be considered when the required number of rooms is determined. When all processes are considered to be deterministic, three rooms are required in the example of Figure 5. The graph shows that more rooms are required when CV increases.

4.3 Case study at a medium-sized hospital

We apply our methods at the pediatric outpatient clinic of the ‘Groene Hart Ziekenhuis’ hospital (GHZ) in Gouda, the Netherlands. GHZ has 450 beds and over 2000 employees [11], and the seven doctors at the pediatric outpatient

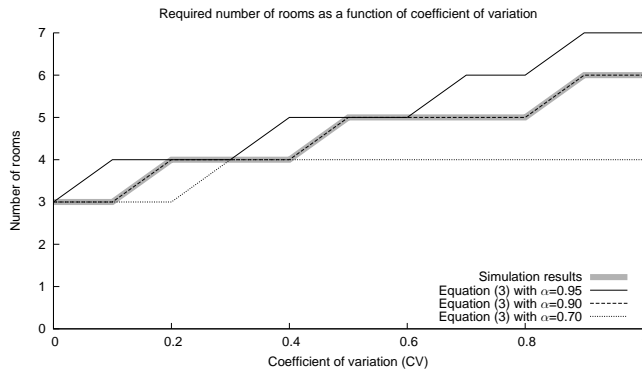


Fig. 5 The required number of rooms when CV increases. All processes are Gamma distributed, with $\mu_P = 10$, $\mu_C = 10$, $\mu_U = 10$, $\mu_T = 1$. The number of rooms in the simulation is chosen such that the doctor utilization can not increase more than 0.5% with an additional room. The simulation results coincide with Equation (3), where $\alpha = 0.90$

clinic consult 12000 patients per year. We focus on a single doctor, who consults patients for nine hours per week. Patients are planned in time slots of 15 minutes. The parameters in Table 6 are the result of extensive data gathering. We know that the DtP-policy outperforms the PtD-policy if we assume that

Table 6 Duration parameters (minutes), retrieved from data for 1875 patients of the pediatric outpatient clinic in 2009

<i>Process</i>	<i>Distribution</i>	<i>Average</i>	<i>Std. deviation</i>
Pre-consultation	Gamma	5.90	6.06
Consultation	Gamma	15.57	8.12
Post-consultation	-	-	-

the doctor's travel time is always lower than the patient's travel time. The simulation results indicate that the DtP-policy outperforms the PtD-policy, when the average travel time does not exceed 6 minutes. In estimating the number of rooms, we assume that travel time is 0.5 minute on average, with $CV = 0.6$. Table 7 shows that three rooms are required, if $\alpha = 0.90$. The fraction of consultations that are in immediate succession (P_{succ} in Table 7) is evaluated numerically with Monte Carlo simulation, and the doctor utilization (*Utilization* in Table 7) is found with our discrete-event simulation.

Table 7 Results to determine the required number of rooms in the case study. The half-length of the 99.9% confidence interval for the doctor utilization is between 0.053% and 0.057%

<i>Number of rooms</i>	<i>P_{succ}</i>	<i>Utilization</i>
2	0.883	92.5%
3	0.984	93.3%
4	0.998	93.3%

5 Conclusion

Inspired by the hospitals ‘RIVAS’ and ‘Groene Hart Ziekenhuis’, who where in the process of redesigning their outpatient clinic, this paper has compared two policies for the organization of outpatient clinics. In the first policy, doctors remain in one consultation room, while patients visit for consultation. We call this the Patient-to-Doctor policy (PtD-policy), and in this policy, the doctor attends the complete patient process: pre-consultation, consultation and post-consultation. In the second policy, patients prepare themselves in individual consultation rooms, with or without the aid of a nurse, while the doctor travels from room to room. We call this the Doctor-to-Patient policy (DtP-policy), and in this policy, the doctor only attends the consultation, and experiences travel time to go from room to room.

We evaluated the two policies on doctor utilization, patient access time and patient waiting time. We provided insight in the ordering of the PtD-policy and the DtP-policy. We show that a hospital should choose the DtP-policy, when for each patient, the doctor’s travel time is lower than the patient’s pre-consultation time. We extend this result with a discrete-event simulation, which indicates that a DtP-policy should be chosen when the average doctor travel time is lower than the sum of the average pre-consultation time and the average post-consultation time. In addition, for the DtP-policy we have determined the required number of rooms, such that the fraction of consultations in immediate succession is maximized.

Both aforementioned hospitals have successfully applied the insights obtained with our methods in the redesign of their outpatient clinics.

References

1. Baesler, F.F., Jahnsen, H.E., DaCosta, M.: Emergency departments I: the use of simulation and design of experiments for estimating maximum capacity in an emergency room. In: S. Chick, P.J. Sánchez, D. Ferrin, D.J. Morrice (eds.) *Proc 35th Conf Winter Simul*, pp. 1903–1906. ACM, New York, NY, USA (2003)
2. Bailey, N.T.J.: A study of queues and appointment systems in hospital out-patient departments, with special reference to waiting-times. *J R Stat Soc* **14**, 185–199 (1952)
3. Boucherie, R.J., Chao, X., Miyazawa, M.: Arrival first queueing networks with applications in kanban production systems. *Perform Eval* **51**(2-4), 83–102 (2003)
4. Brahim, M., Worthington, D.J.: Queueing Models for Out-Patient Appointment Systems—A Case Study. *J Oper Res Soc* **42**(9), 733–746 (1991)
5. Buitenhek, R.: Performance evaluation of dual resource manufacturing systems. Ph.D. thesis, University of Twente, The Netherlands (1998)
6. Cayirli, T., Veral, E.: Outpatient scheduling in health care: a review of literature. *Prod Oper Manag* **12**(4), 519–549 (2003)
7. Chand, S., Moskowitz, H., Norris, J.B., Shade, S., Willis, D.R.: Improving patient flow at an outpatient clinic: study of sources of variability and improvement factors. *Health Care Manag Sci* **12**(3), 325–340 (2009)
8. Côté, M.J.: Patient flow and resource utilization in an outpatient clinic. *Socio-Econ Plan Sci* **33**(3), 231–245 (1999)
9. De Angelis, V., Felici, G., Impelluso, P.: Integrating simulation and optimisation in health care centre management. *Eur J Oper Res* **150**(1), 101–114 (2003)
10. Duguay, C., Chetouane, F.: Modeling and improving emergency department systems using discrete event simulation. *Simul* **83**(4), 311–320 (2007)
11. GHZ Website: Website of Groene Hart Ziekenhuis (In Dutch) (2010). <http://www.ghz.nl>. Accessed 16 April 2010.
12. Harper, P.R., Gamlin, H.M.: Reduced outpatient waiting times with improved appointment scheduling: a simulation modelling approach. *OR Spectr* **25**(2), 207–222 (2003)
13. Ho, C.J., Lau, H.S.: Minimizing total cost in scheduling outpatient appointments. *Manag Sci* **38**(12), 1750–1764 (1992)
14. Isken, M.W., Ward, T.J., McKee, T.C.: Simulating outpatient obstetrical clinics. In: P.A. Farrington, H.B. Nembhard, D.T. Sturrock, G.W. Evans (eds.) *Proc 31st Conf Winter Simul*, pp. 1557–1563. ACM, New York, NY, USA (1999)
15. Jiang, L., Giachetti, R.E.: A queueing network model to analyze the impact of parallelization of care on patient cycle time. *Health Care Manag Sci* **11**(3), 248–261 (2008)
16. Johnston, M.J., Samaranayake, P., Dadich, A., Fitzgerald, J.A.: Modelling radiology department operation using discrete event simulation (2009). Working paper.
17. Kopzon, A., Nazareth, Y., Weiss, G.: A Push–Pull Network with Infinite Supply of Work. *Queueing Syst* **62**(1), 75–111 (2009)
18. Law, A.M.: Simulation modeling and analysis, fourth edn. McGraw-Hill (2009)
19. Levy, H., Sidi, M.: Polling systems: Applications, modeling, and optimization. *IEEE Trans Commun* **38**(10), 1750–1760 (1990)
20. Robinson, L.W., Chen, R.R.: Scheduling doctors’ appointments: optimal and empirically-based heuristic policies. *IIE Trans* **35**(3), 295–307 (2003)
21. Swisher, J.R., Jacobson, S.H.: Evaluating the design of a family practice healthcare clinic using discrete-event simulation. *Health Care Manag Sci* **5**(2), 75–88 (2002)
22. Swisher, J.R., Jacobson, S.H., Jun, J.B., Balci, O.: Modeling and analyzing a physician clinic environment using discrete-event (visual) simulation. *Comput Oper Res* **28**(2), 105–125 (2001)
23. Takagi, H.: Queueing analysis of polling models: progress in 1990–1994. In: *Frontiers in queueing: models and applications in science and engineering*, pp. 119–146. CRC Press, Inc., Boca Raton, FL, USA (1998)
24. Vissers, J., Beech, R.: *Health operations management: patient flow logistics in health care*. Routledge (2005)
25. Zonderland, M.E., Boer, F., Boucherie, R.J., de Roode, A., van Kleef, J.W.: Redesign of a university hospital preanesthesia evaluation clinic using a queueing theory approach. *Anesth Analg* **109**(5), 1612–1614 (2009)