Redesign of a University Hospital Preanesthesia Evaluation Clinic Using a Queuing Theory Approach

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BACKGROUND: Changes in patient length of stay (the duration of 1 clinic visit) as a result of the introduction of an electronic patient file system forced an anesthesia department to change its outpatient clinic organization. In this study, we sought to demonstrate how the involvement of essential employees combined with mathematical techniques to support the decision-making process resulted in a successful intervention.

METHODS: The setting is the preanesthesia evaluation clinic (PAC) of a university hospital, where patients consult several medical professionals, either by walk-in or appointment. Queuing theory was used to model the initial set-up of the clinic, and later to model possible alternative designs. With the queuing model, possible improvements in efficiency could be investigated. Inputs to the model were patient arrival rates and expected service times with clinic employees, collected from the clinic's logging system and by observation. The performance measures calculated with the model were patient length of stay and employee utilization rate. Supported by the model outcomes, a working group consisting of representatives of all clinic employees decided whether the initial design should be maintained or an intervention was needed.

RESULTS: The queuing model predicted that 3 of the proposed alternatives would result in better performance. Key points in the intervention were the rescheduling of appointments and the reallocation of tasks. The intervention resulted in a shortening of the time the anesthesiologist needed to decide upon approving the patient for surgery. Patient arrivals increased sharply over 1 yr by more than 16%; however, patient length of stay at the clinic remained essentially unchanged. If the initial set-up of the clinic would have been maintained, the patient length of stay would have increased dramatically.

CONCLUSIONS: Queuing theory provides robust methods to evaluate alternative designs for the organization of PACs. In this article, we show that queuing modeling is an adequate approach for redesigning processes in PACs.

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In the past 2 decades, it has become common practice to provide preoperative screening in an outpatient clinic setting.[1–3] Lee[4] was the first to outline the concept of the preanesthesia evaluation clinic (PAC). He stated that the purpose of the preoperative screening process is "to examine and treat the patient, so that he will arrive in the operating theater as strong and as healthy as possible," a definition that still adequately defines the process. Today, many hospitals operate a PAC.[3] An accurately performed screening reduces the risk of cancellation on the day of surgery due to the physical condition of the patient,[5] increases the rate of same-day admissions, and reduces perioperative morbidity, resulting in decreased costs and increased quality of care.[6,7]

Congestion is a common phenomenon in outpatient clinics.[8–10] Patients arriving for a preoperative screening are usually not categorized, and therefore the consultation time needed per patient is difficult to estimate. This increases the complexity of the PAC organization compared with a regular outpatient clinic. In our own PAC, patient waiting times and length of stay (the total duration of 1 clinic visit) were initially significantly shorter than in a comparable clinic,[11] but these increased dramatically after introduction of an electronic patient data management system, because together with the information system additional administrative activities were introduced. Also, the workload of the staff increased, leading to multiple complaints about work stress. The prolonged waiting times, together with the low level of job satisfaction for clinic employees, called for an evaluation of alternative clinic designs. The aim of this study was to explore possibilities for a more efficient operation of our PAC organization. Because all patient

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movement within the PAC was logged, we chose to use mathematical techniques to analyze performance.

The major advantage of mathematical modeling is the possibility to execute a thorough analysis of a system, while having no impact on the system itself. Using our mathematical model, we investigated the effect of various designs on selected performance measures, such as patient length of stay and staff utilization rate (the fraction of time clinic staff is occupied with patient-related activities). An advantage of using mathematical techniques, compared with other reengineering approaches such as lean health care management or theory of constraints, is that they allow for a quantified comparison of current performance and expected performance of alternative clinic designs. One of the alternative designs we considered was regarded as superior to the initial design by the clinic staff. This design was implemented at our PAC in 2007. After the intervention, an unexpected increase of 16% in patient visits in the first quarter of 2008 occurred. However, this did not cause a significant increase in waiting times, and in addition resulted in a decrease of employee costs per patient. Furthermore, the time needed to approve a patient for surgery decreased, and employee satisfaction increased. This article describes the redesign process and provides directions for other PAC managers.

This study is based on a queuing modeling approach. Simulation is a more common approach in this area. In 1952, Bailey[12] had already used Monte Carlo simulation to analyze appointment systems for outpatient clinics. Since then, simulation has been used extensively for the study of outpatient clinics. Within the scope of the PAC, simulation was used to analyze the capacity needed to shorten the waiting list[11] and to study the design of appointment systems for the PAC to minimize patient waiting times.[8] The choice for using simulation techniques is not always supported by clear argumentation.[13] Simulation modeling is a powerful tool but it is time-consuming due to the effort it takes to build the model into a simulation software program. Moreover, it requires detailed information on the input distribution such as those of the consultation time, or the patient arrival processes. An analytical (queuing) model requires fewer data.[14] In particular, our queuing modeling approach requires only mean and variance of consultation times and patient arrival processes, and no further assumptions on the underlying distributions. Because of the careful analysis required before the formulation of the equations used in the model, a robust insight into the underlying relationships of the system is obtained. In this article, we show that queuing modeling is an adequate approach for redesigning processes in an outpatient clinic. Applications of queuing theory in outpatient clinic settings are scarce. The majority of articles published on this matter are covered by Preater[15] in his extensive bibliography on queues in health.

One of the advantages of simulation modeling compared with queuing modeling is the possibility to consider any desired system characteristic. This is, at the same time, also one of the major drawbacks of this method, because one might get lost in the details and lose sight of the real problem. As can be seen in the Appendix, the queuing model presented in this article consists of several related formulas that can be entered into a spreadsheet. It enables a bottleneck analysis of the processes at the clinic and can easily be adjusted so that it represents one of the alternative designs considered in the redesign process. It is also possible to adjust the model so that it represents a preanesthesia clinic at another hospital.

METHODS

Initial Service of the PAC

The study was performed at a university hospital PAC, with approximately 6000 patient visits annually. A majority of patients were seen on walk-in basis (about 70%), and the remaining on appointment basis. Walk-in patients arrived directly from surgical outpatient clinics within the hospital. Only ASA physical status I or II patients were evaluated on walk-in basis, because for ASA physical status III or IV patients, more time for patient contact and additional information from other specialists were often required. It was clinic policy to maximize the number of walk-in patients; nevertheless, these patients posed an uncertain demand on clinic resources. Although fewer than 10% of patients were classified ASA physical status III or IV and therefore required an appointment, 30% of all patients were given an appointment. When walk-in patients were deferred to an appointment, it was usually because of overcrowding in the waiting room.

Resources and Tasks

The clinic was run by the Department of Anesthesiology, with 4 anesthesia care providers attending: 1 staff anesthesiologist, 2 residents, and a nurse practitioner, supported by a secretary and 2 clinic assistants. The screening process consisted of at most 3 steps: an intake with the secretary and 2 separate contacts with the clinic assistant and anesthesia care provider, respectively. All patients would see the secretary and anesthesia care provider, but only adults were seen by the clinic assistant. Patients returned to the waiting room between visiting each care provider (Fig. 1). Based on a form completed by the referring specialist, the secretary decided whether the patient could be assessed immediately or during an appointment at a later time. Because the secretary is not equipped to make decisions regarding the medical status of the patient, this procedure resulted occasionally in patients receiving an appointment they did not need and *vice versa*. If the patient received an appointment, the time interval, usually 1 or 2 wk, was used for back-office activities to complete the patient's file. Walk-in

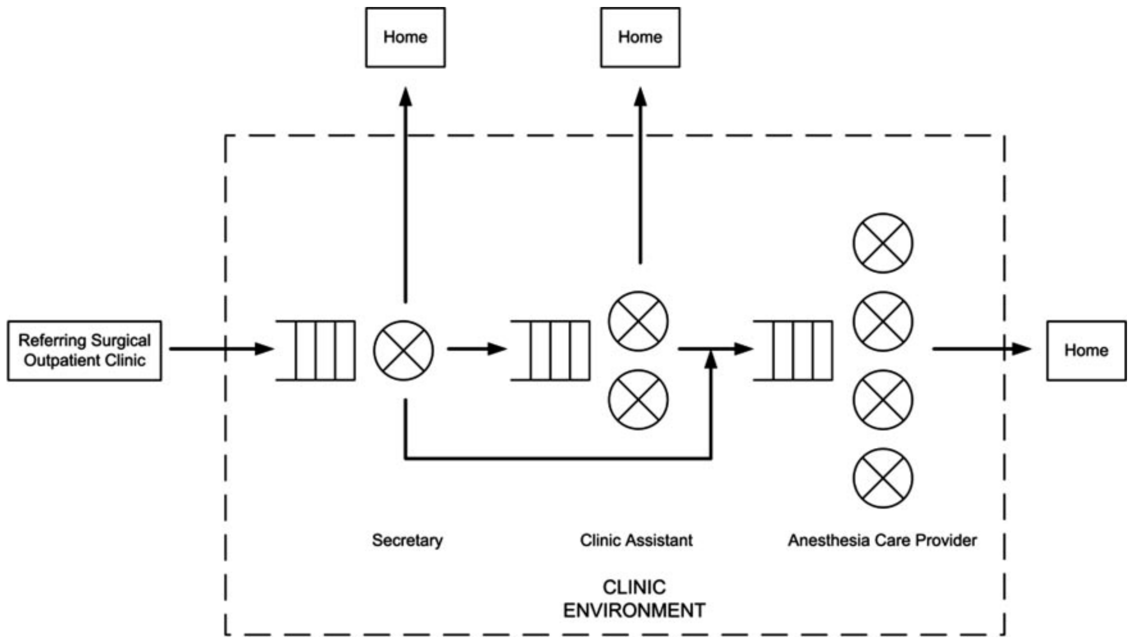

Figure 1. Diagram of clinic operations.

patients were approved for surgery by the anesthesia care provider during their visit. The staff anesthesiologist performed the back-office activities, consisting mostly of processing additional patient information that was required to finish the case of appointment patients. Because the staff anesthesiologists also served as backup manpower for the front-office activities, they experienced significant work stress. Furthermore, the anesthesia care providers were unhappy because complicated cases had to be finalized by an anesthesia care provider who had not seen the patient initially, which ultimately may result in an incomplete understanding of the medical condition of the patient.[16]

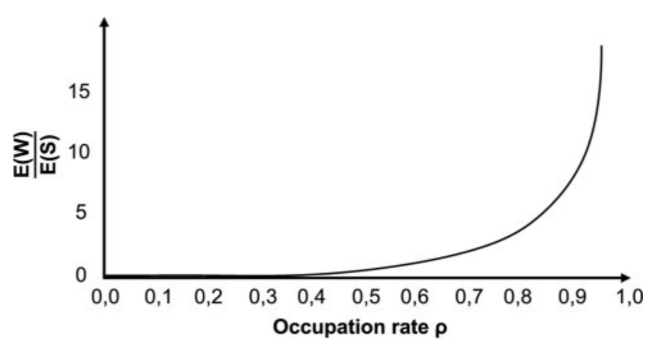

Figure 2. The Pollaczek-Khintchine curve. E(W) = mean waiting time; E(S) = mean service time.

Using Queuing Theory to Analyze PAC Performance

The initial and alternative designs were compared with a Multi-Class Open Queuing Network Model (for a detailed description, see the Appendix). An advantage of this queuing model is that only the first 2 moments (mean and standard deviation) of the arrival rate and service time distributions are needed in the calculations. This allows usage of all possible types of distributions, including empirical distributions. For the comparison, 2 performance measures were calculated with the queuing model, namely, patient length of stay and employee utilization rate (ρ). In the recent work by Jiang and Giachetti,[17] the authors briefly describe a survey held at their outpatient clinic. From the survey, it followed that patients considered the waiting time—an important contributor to the length of stay—as very important and unsatisfactorily long. Other aspects, such as the consultation with the anesthesia care provider and the clinic assistant, also contribute to the patient's contentment on the clinic visit.[18] Employee utilization rate, ρ, and the patient's waiting time to see this specific employee, $E(W_Q)$, are related. As an example, consider the single server queue with Poisson arrivals and general service times (in the queuing model of the PAC, the employees act as servers). The relationship between server utilization rate ρ and waiting time $E(W_Q)$ is described by the Pollaczek-Khintchine formula[19]:

$$\frac{E(W_Q)}{E(S)} = \frac{\rho}{1-\rho}\frac{1+SCV_S}{2},$$

where E(S) denotes the expected service time and SCV_S the squared coefficient of variation of the service time. This nonlinear relationship is shown in Figure 2. The server utilization rate ρ equals the arrival rate λ multiplied by the expected service time E(S). The system should be able to deal on average with the offered load ρ, and therefore it is required that the number of arrivals per unit of time is strictly smaller than the number of customers that can be served per unit of time (so $\rho < 1$). It is apparent that an increase in the server utilization rate from 0.4 to 0.5 has only little impact, whereas an increase from 0.8 to 0.9 results in more than double the original waiting time. An increase from 0.9 to 0.99 even results in an increase of the waiting time by a factor 10. Knowledge of the utilization rate of a system is essential, because increasing this factor when it is already close to 1, by increasing either the arrival rate or the service time, will result in a considerable increase of the waiting time.

Intervention

All parties involved thought that the situation at the PAC required an intervention. A working group was formed with representatives of all PAC employees. The working group discussed the initial (i.e., the in-place) design and developed 4 alternative designs, which are described in the subsequent paragraphs. When discussing the initial design, the working group identified all relevant activities at the PAC and characterized the order of these activities in the initial design in several flow charts. Ultimately, the working group decided on the planned design from the presented alternatives. Again, the order of all activities in the new design was documented in several flow charts and medical protocols. The queuing model results were used to guide the decision-making process and enabled a numerical comparison of the initial and alternative clinic designs.

Alternative Design 1: Clinic Assistant Selects at Front Desk

The clinic assistants were convinced that many patients with an actual ASA physical status III or IV score were assigned an erroneous ASA physical status I or II score by the secretary. These miscategorized patients were then handled on walk-in basis and consumed too much time in the office of the anesthesia care provider, resulting in congestion in the waiting room. They suggested that one of the clinic assistants should take over part of the front desk task from the secretary, while the other clinic assistant performs measurements and blood sampling.

Alternative Design 2: Treat All Patients on Appointment Basis

Demand for an outpatient clinic's services can be divided into 2 components: controlled (appointment patients) and uncontrolled (walk-in patients) demand.[20] In the initial set-up, most ASA physical status I or II patients were seen as walk-in patients. In the second alternative, all patients are deferred to an appointment, because a clinic with an appointment-only system will always provide a better service level with respect to patient waiting times than a clinic that allows walk-in arrivals.[8]

Alternative Design 3: Reschedule Appointments

Rising et al.[20] suggested scheduling appointments such that they complement walk-in arrivals. This results in a more homogeneous arrival pattern throughout the day. In the PAC under study, the number of walk-in arrivals was significantly lower in the early morning and on Friday afternoon. In this alternative, all appointments are scheduled in these periods.

Alternative Design 4: Regroup Employee Tasks and Amend Patient Flows

In this alternative, the secretary accepts all patients; therefore, all patients are seen by the clinic assistant on their first visit. Clinic assistants are provided with protocols to aid in the decision whether the patient can be seen immediately based on the extent of comorbidity, contacts with medical specialists, and the requirement to obtain additional medical information before the visit to the anesthesiologist. If the patient requires additional testing, these tests are immediately performed and/or requested and the patient is deferred to an appointment, scheduled when all additional information is available. Consequently, the patient can be approved for surgery when the appointment takes place.

RESULTS

Model Input

Data from all PAC visits recorded in the first quarter of 2007 were used to obtain input parameters for the queuing model (n = 1492). For the analysis, patients were divided in 3 separate classes: 1) children (<16 yr old), 2) adult patients ASA physical status I or II, and 3) adult patients ASA physical status III or IV. This classification was chosen because children and adults have a different routing; moreover, the 3 classes can be distinguished by how much time each requires in consultation with the anesthesia care provider. An advantage of this classification is that it is similar to that used by clinic staff. Arrival rates for each patient class and mean and standard deviation of the contact time with the clinic assistant and anesthesia care provider were determined. Not all registered contacts had complete data, and therefore the records of 1293 patients (87%) could be used for the latter part of the data analysis. The time patients spent with the secretary was not recorded and therefore we used an estimate. The secretary was often consulted by coworkers who inquired after the approval status of a particular patient, either by phone or in person at the reception desk. The secretary was also responsible for dealing with patient inquiries, either on the phone or in person. The anesthesia care providers were often consulted by coworkers, and the inquiries usually concerned their other professional responsibilities. We estimated that regarding the time available for direct contact with patients visiting the clinic for a consult, the secretary lost 50% and the anesthesia care providers lost 33% because of these interferences. The values were obtained by direct observation and interviewing the employees. Even though the aforementioned tasks do not directly contribute to the patient's visit at the clinic, they need to be done and are part of the job in our hospital organization.

Table 1. Summary of Input Data

Patient class	N	Appointment percentage	Arrival rate	Service time secretary		Service time clinic assistant		Service time anesthesia care provider	
				$E(S)$[a]	sd(S)[b]	$E(S)$	sd(S)	$E(S)$	sd(S)
Children	274	15	0.79	5.00	5.00	—	—	24.30 (n=274)	20.64
Adults ASA physical status I or II	902	25	2.60	5.00	5.00	10.71 (n=711)	8.97	27.24 (n=902)	17.26
Adults ASA physical status III or IV	117	78	0.34	5.00	5.00	16.31 (n= 86)	14.20	52.05 (n=117)	25.50
Deferred to appointment	—	—	1.04	2.50	2.50	—	—	—	—

[a] Mean service time in minutes.

[b] Standard deviation of service time in minutes.

Table 2. Adjustment of Input Parameters for Evaluation of Alternative Designs[a]

Alternative	Adjustment	Explanation
1[b]	$s_2 = 1$	One clinic assistant moves to secretary station.
	$e_1 = 1$	No disturbance during welcoming of patients.
2[c]	$\zeta_1 = 3.73$ $SCV_{A,2,1} = 0$ $SCV_{A,3,1} = 0$ $SCV_{A,4,1} = 0$	The secretary gives all patients an appointment the first time they arrive at the PAC, thus arrival rate increases. We assume that appointment patients arrive on time. Therefore, the standard deviation of their arrival time equals 0, which results in an SCV equal to 0.[d]
3[e]	$\zeta_2 = 1.93$ $\zeta_3 = 0.07$ $\zeta_4 = 0.67$	Appointments are rescheduled outside the interval 10 am to 4 pm, and therefore the fraction of patients with an appointment is removed from the arrival rates.
4[f]	$\zeta_1 = 0$	No patients are deferred to an appointment by the secretary.
	$E(S_{r,1}) = 2.50$ $E(S_{2,2}) = 15.71$[g] $E(S_{3,2}) = 21.31$	Consultation time at secretary decreases with 2.5 min, because part of tasks are reallocated to clinic assistants; consultation times at clinic assistants increases with these 2.5 min and with an additional 2.5 min needed to determine upon additional testing.
	$SCV_{A,5,1} = 0$ $SCV_{A,6,1} = 0$ $SCV_{A,7,1} = 0$	We assume that appointment patients arrive on time. Therefore, the standard deviation of their arrival time equals 0, which results in an SCV equal to 0.

PAC = preanesthetic evaluation clinic.

[a] All other parameter values remain constant.

[b] Clinic assistant selects at front desk.

[c] Treat all patients on appointment basis.

[d] Patients are assumed to arrive on appointment basis with fixed and identical interarrival times, so as to analyze the maximal possible benefit of an appointment scheme. Hence, the standard deviation equals zero for all patient classes.

[e] Reschedule appointments.

[f] Regroup employee tasks and amend patient flows.

[g] We assumed that the ratio between expectation and variance of the contact time at the clinical assistants (and therefore also the SCV) remained constant.

The number of arrivals per patient class was used to determine the distribution of patients among classes. We found that the majority of patients arrived between 10 AM and 4 PM. Hence, we focused our analysis on this interval and calculated the arrival rate (3.73 patients/h) by using patient arrivals recorded during this interval. We observed that within this period, patients from all classes arrived in a homogeneously distributed manner. This corresponds with the squared coefficient of variation (Appendix) of the arrival process being equal to 1 for all patient classes. The arrivals of patients who were immediately deferred to an appointment were not recorded. Assuming that all appointment patients make their appointments at the reception desk, we calculated the arrival rate of nonadmitted patients by multiplying the admitted patient arrival rate by the appointment percentage for each patient class. A summary of input data is given in Table 1. Senior clinic staff members discussed and carefully checked all parameter values; additionally, they discussed and approved the queuing model design.

Comparison of Initial Design and Alternatives

With the model, we compared each alternative design with the initial design. If necessary, input parameters were adjusted (see Table 2 for the modifications and the Appendix for an explanation of the parameters). The performance measures we chose to compare were expected patient length of stay (the total duration of 1 clinic visit) and employee utilization rate. The initial design could be characterized by a long expected patient length of stay, caused by prolonged waiting times at the secretary and later in the process, before the contact with the anesthesia care provider (Table 3). These 2 care stations also had high

Table 3. Results of Analytical Model

Design	Secretary		Clinic assistant		Anesthesia care provider		Patient length of stay[c]
	ρ^a	$E(W)^b$	ρ	$E(W)$	ρ	$E(W)$	
Initial	0.68	19.20	0.28	0.60	0.67	9.60	77.35
Alternative I[d]	0.34	2.40	0.56	12.60	0.67	9.00	71.95
Alternative II[e]	0.90	54.00	0.28	0.60	0.67	9.60	107.15
Alternative III[f]	0.51	9.60	0.18	0.60	0.45	1.80	59.95
Alternative IV[g]	0.38	3.00	0.40	2.40	0.67	9.60	62.95
Alternative III + IV	0.30	2.04	0.40	2.63	0.44	1.60	54.22

[a] Occupation rate.

[b] Mean waiting time in minutes.

[c] Mean patient length of stay in minutes, for the most common group of patients (adult ASA physical status I/II walk-in).

[d] Clinic assistant selects at front desk.

[e] Treat all patients on appointment basis.

[f] Reschedule appointments.

[g] Regroup employee tasks and amend patient flows.

utilization rates. Comparing the performance measures of the initial design to those of the alternative designs led to the conclusion that all alternative designs, except alternative 2 (treat all patients on appointment basis), would result in a better overall performance.

Once the model results were available, the working group was consulted to make a decision on the next step to take in the redesigning process. It was apparent to all members that the initial design could not be maintained. The first alternative of relocating 1 clinic assistant to the secretary's station was not regarded as a valuable alternative, because the expected decrease in patient length of stay was minimal. Furthermore, patient waiting time at the remaining clinic assistant increased substantially, which was also undesirable. Based on the predicted increase in patient waiting time for the secretary in alternative 2, which was caused by all patients having to make an appointment first, and because introducing an appointment-only system was regarded as patient unfriendly (in the sense of one-stop shopping) by the working group, alternative 2 was eliminated. The working group members decided to implement alternatives 3 and 4, so that advantages of both alternatives were included. The effects of combining alternatives 3 and 4 were again studied with the queuing model (Table 3). The queuing model predicted that this intervention would also result in an improvement. Supported by the results, all working group members were convinced that implementing a combination of the 2 alternatives would yield a better overall performance of the clinic.

Effect of Intervention

The new design was implemented in the summer of 2007. We compared actual measured times of total patient length of stay before and after the intervention. To minimize seasonal influences and to allow for learning effects, we used data from both the first quarter of 2007 and 2008. Before the intervention, only 1 clinic assistant was present on Fridays. Because the intervention involved scheduling the majority of appointments on Fridays, 1 additional clinic assistant shift was now required. This caused an increase in total employee capacity from 7.20 (total costs: 109K Euros/quarter) to 7.87 full-time employees (total costs: 116K Euros/quarter, +6%). Before the intervention, the total length of stay as obtained from the measurements over a 90-day period (January 1, 2007 to March 31, 2007) was on average 70.0 min (95% confidence interval [CI]*: 62.8–77.1). After the intervention, the total length of stay as obtained from the measurements over a 91-day period (January 1, 2008 to March 31, 2008) was on average 77.0 min (95% CI: 70.6–83.3). Although the total length of stay did not increase significantly, longer contact and waiting times for the clinic assistant were measured (95% CI of increase in contact times: 5.5–7.6, 95% CI of waiting times in 2007: 8.6–25.1, 95% CI of waiting times in 2008: 25.8–30.3). Recall that not all patients see the clinic assistant and therefore the increase in total patient length of stay was less. The contact and waiting times for the anesthesia care provider did not increase significantly (95% CI of increase in contact times: −1.5 to 1.5, 95% CI of waiting times in 2007: 19.6–26.9, 95% CI of waiting times in 2008: 19.8–28.1). In the first quarter of 2008, 1737 patient contacts were registered during the opening hours of the clinic, an increase of 245 patients (+16%) compared with the first quarter of 2007. Dividing the total personnel costs by the number of patients for both quarters, we see that personnel costs decreased from 73 to 67 Euros per

*All CIs in the Results section, except those considering patients' waiting times and total length of stay, were calculated as follows: $(1 - \alpha)\%$ CI $= (X \pm c\ S/\sqrt{n})$, where X is the sample mean, S the sample standard deviation, n the number of observations in the sample, and $c = \phi^{-1}(1 - ½\alpha)$, with ϕ^{-1} the inverse of the standard normal cumulative distribution function. The CIs regarding waiting times and total length of stay were calculated with a batch means method using batches holding 50 observations, where X and S in the above formula are substituted by the batch mean and batch standard deviation, respectively, and n is the number of batches.

Table 4. Results of Analytical Model with 2008 Data[a]

Design	Secretary		Clinic assistant		Anesthesia care provider		Patient length of stay[d]
	ρ^b	$E(W)^c$	ρ	$E(W)$	ρ	$E(W)$	
Initial	0.81	38.24	0.35	1.46	0.83	30.38	118.03
Alternative III + IV[e]	0.37	2.80	0.50	4.75	0.63	6.70	62.20

[a] Arrival rates: children 0.87, adults ASA physical status I or II 3.32, adults III or IV 0.41, deferred to appointment 0.88.

[b] Occupation rate.

[c] Mean waiting time in minutes.

[d] Mean patient length of stay in minutes, for the most common group of patients (adult ASA physical status I/II walk-in).

[e] Reschedule appointments, regroup employee tasks, and amend patient flows.

patient (−8%). The percentage of patients seen on walk-in basis increased from 72% in 2007 to 81% in 2008. Furthermore, in 2008, the anesthesiologist needed 6.8 days to decide upon approving the patient for surgery, compared with 7.9 days in 2007 (95% CI: −0.3 to 2.3). The staff anesthesiologists were responsible for finalizing the status of those patients for whom new information was obtained in the days or weeks after the patient had visited the PAC. After the intervention, this task was minimal (<30 min), because for most patients all relevant information was available before the first visit to the attending anesthesia care provider.

Validity of the Model

The average length of stay of the most common group of patients (walk-in patients with ASA physical status I and II) measured at the clinic in the first quarter of 2007 (70.6 min) was slightly less than predicted with the queuing model (77.4 min, −9%), and thus the queuing model provided a conservative but close prediction of system behavior. When comparing the average length of stay for the same patient group measured in the first quarter of 2008 (77.9 min) with the model's prediction (62.2 min), we see that the model underestimated the length of stay by 25%. However, we found that in the new clinic design, the secretary was not able to halve her consultation time, because her remaining tasks required more time than expected before the intervention. If we incorporate this in the queuing model and use the original consultation time, we come to a length of stay equal to 90.4 min (−14%), and the queuing model again gives a conservative estimate. The validity of the model outcomes highly depends on the parameter values.

DISCUSSION

We demonstrated a queuing modeling approach that enables a fast and robust analysis of PAC performance. The methodology can be applied to other preoperative screening clinics as well. Given the queuing model results, the PAC was redesigned. This process consisted of 2 parts, namely, the rescheduling of appointments to the early morning and Friday, and the reassignment of tasks from the secretary to the clinic assistants. As a consequence, all patients were seen on their walk-in visit by the clinic assistant. Patients requiring more contact time with the anesthesia care provider or back-office activities were deferred to an appointment by the clinic assistant, scheduled when all required information was available. Literature about the redesign of hospital care is extensive.[21] However, the literature on redesign of outpatient and PACs is limited. Some studies were dedicated to the design of appointment systems,[8] but others concentrated largely on waiting times and patient satisfaction.[11,22] The concept of redesign by reallocating tasks at the outpatient clinic has received less attention.

A limitation of this study is that all outcomes of the queuing model were calculated under the assumption of steady-state behavior. The system under study will never reach this equilibrium state because of inhomogeneous patient arrivals and restrictive opening hours. We used the queuing model solely for comparison purposes and not for prediction of actual patient length of stay and utilization rates, which further strengthened our confidence in the approach we followed.

The model enabled us to analyze the effect of increased pressure on the clinic. As mentioned in the Results section, patient arrivals had increased 16% in the first quarter of 2008, compared with the same period in 2007. Nevertheless, empirical analysis showed that patient length of stay had only increased slightly. The model shows that the increase in patient arrivals would have resulted in a tremendous increase in patient length of stay and employee utilization rate if we had not changed the design of our PAC (Table 4). Using the 2008 data, the initial design operates under high pressure, with an increase in length of stay of 53%, due to the 16% increase in patient arrivals. In the implemented design, due to increased efficiency, the system operates under modest pressure, with an increase in length of stay of only 15% (Table 4). This is in line with the relationship depicted in Figure 2, indicating the typical relationship between waiting time and load. By organizing the processes at the clinic more efficiently, we reduced the load and moved left on the curve. Therefore, the increase in patient arrivals did cause an increase in the load but only a slight increase in waiting time and patient length of stay.

The majority of patients visiting our PAC are seen on a walk-in basis. Because patients have the opportunity to go straight from the surgical outpatient clinic to the PAC, they are often able to finalize the entire preoperative preparation within 1 hospital visit (1-stop shopping), avoiding multiple hospital visits. However, walk-in outpatient clinics are notoriously more difficult to handle in terms of optimizing waiting times for patients and peak pressures for anesthesia care providers. Dexter[8] states that the best service walk-in PACs can provide will always be worse than appointment PACs. The walk-in PAC requires more resources to have acceptable waiting times for patients,[11] because more slack is required to deal with unexpected peaks in patient arrival. Appointment systems, on the other hand, deal with peaks in demand for PAC services by building waiting lists. To allow for patients who need to be seen with some urgency, these appointment-only outpatient clinics will usually have some unplanned time slots (or add-on manpower). At the PAC under study, we use a system that allows both walk-in and appointment patients. The decrease of back-office activities enabled the anesthesia care providers to dedicate more time to patient contact. This explains how 16% more patients could be seen without an increase in the number of anesthesia care providers.

APPENDIX: THE QUEUING MODEL

With the Multi-class Open Queuing Network Model, we derived measures to analyze performance of our PAC. There are many books that give an introduction to queuing theory; see, for example, Taylor and Karlin.[23] The extensive bibliography by Preater[15] provides many examples of queuing theory applications in health care. The article by Jiang and Giachetti[17] gives an example of a multiclass open queuing network model applied to an outpatient clinic. A queuing network model represents a set of connected queues. At the PAC, there are 3 separate queues where the employees act as servers. The secretary station is a single server queue, whereas the clinic assistant and anesthesia care provider station are multiserver queues. Patients enter the queuing network via the secretary station and finally depart from the system. Furthermore, if upon arrival at a station an employee is available, patients are served immediately; otherwise, they join the queue in first-come first-serve discipline. We use the approximate decomposition method[24] to analyze the model. The approximate decomposition method has an advantage that only the mean and squared coefficient of variation (SCV) of the arrival process and contact times are needed (the SCV equals the variance divided by the squared mean).

First, we introduce some notations. There are r distinct patient classes, where $r = 1$ are patients deferred to an appointment by the secretary, $r = 2$ adults ASA physical status I or II, $r = 3$ adults ASA physical status III or IV, and $r = 4$ are children. To evaluate alternative design 4, we also introduce $r = 5$, 6, 7 to represent patients (adults with ASA physical status I or II, adults with ASA physical status III or IV, and children, respectively) who return for their appointment. We have i stations, $i = [1..3]$ representing the secretary, clinic assistant, and anesthesia care provider. In the model analysis, we follow the 3 steps from the approximate decomposition method.

Step 1: Reduction to a Single Class Open Queuing Network

Figure 1 gives the Single Class Open Queuing Network resulting from the aggregation of the patient flows. The aggregated arrival rates at station i are

$$\lambda_1 = \sum_{r=1+d}^{4+3d} \zeta_r,\ \lambda_2 = \sum_{r=2}^{3} \zeta_r,\ \lambda_3 = \sum_{r=2}^{4} (1 - da_r)\zeta_r + d\sum_{r=5}^{7} \zeta_r,$$

where ζ_r is the arrival rate of patient class r at station 1, and a_r is the fraction of patients of class r who are deferred to an appointment in alternative design 4. Because the indexes $r = 5, 6, 7$ only exist when alternative design 4 is evaluated, we introduce the binary variable d, which equals 1 if alternative design 4 is evaluated and 0 otherwise.

The utilization rates per patient class for stations 1, 2, and 3 are

$$\rho_{1,r} = \zeta_r E(S_{r,1}) \frac{1}{e_1 s_1} \text{ for } r = 1 + d,\ldots,4 + 3d,$$

$$\rho_{2,r} = \zeta_r E(S_{r,2}) \frac{1}{s_2} \text{ for } r = 2,3, \text{ and}$$

$$\rho_{3,r} = \zeta_r E(S_{r,3}) \frac{1}{e_3 s_3} + d(1 - a_r)\zeta_r E(S_{r,3}) \frac{1}{e_3 s_3} \quad \text{for } r = 2,\ldots,4 + 3d,$$

where $E(S_{r,i})$ is the mean service time for patient class r at station i. Because the secretary is often consulted by other patients and coworkers while helping a patient at the reception desk, an effective capacity e_1, $0 < e_1 \leq 1$, is taken into account when calculating the mean time a patient spends at this station. The anesthesia care provider is not consulted by coworkers while treating patients and therefore the effective capacity e_3, $0 < e_3 \leq 1$, is only used in calculating the utilization rate. As mentioned in the Results section, these effective capacities were calculated by using direct observations and interviews with the employees. The number of servers (i.e., employees) at station i equals s_i.

Adding the utilization rates over all patient classes for stations 1, 2, and 3 gives the aggregated utilization rates.

$$\rho_1 = \sum_{r=1+d}^{4+3d} \rho_{1,r},\ \rho_2 = \sum_{r=2}^{3} \rho_{2,r},\ \rho_3 = \sum_{r=2}^{4+3d} \rho_{3,r}$$

For stability, it is required that $\rho_i < 1$ for all i.

Step 2: Analysis of the Single Class Open Queuing Network

The arrival process at station 1 has SCV

$$SCV_{A,1} = w_1 \sum_{r=1+d}^{4+3d} Q_{r,1} SCV_{A,r,1} + 1 - w_1,$$

where $SCV_{A,r,1}$ is the SCV of the arrival process of patient class r at station i, and

$$w_1 = \frac{1}{1 + 4(1-\rho_1)^2(v_1 - 1)}, \; v_1 = \frac{\lambda_1^2}{\sum_{r=1+d}^{4+3d} \zeta_r^2}, \; Q_{r,1} = \frac{\zeta_r}{\lambda_1}.$$

The mean service time and SCV at station 1 are

$$E(S_1) = \frac{1}{\lambda_1} \sum_{r=1+d}^{4+3d} \zeta_r E(S_{r,1}),$$

$$SCV_{s,1} = \frac{1}{\lambda_1 E^2(S_1)} \sum_{r=1+d}^{4+3d} \zeta_r E^2(S_{r,1})(SCV_{S,r,1} + 1) - 1,$$

where $SCV_{S,r,i}$ is the SCV of the service time for patient class r at station i.

The arrival process at station 2 has SCV

$$SCV_{A,2} = P_{1,2} SCV_{D,1} + 1 - P_{1,2}$$

where $SCV_{D,1}$ is the SCV of the departure process at station 1 and $P_{1,2}$ is the portion of the aggregated flow out of station 1 to station 2.

$$SCV_{D,1} = (1-\rho_1^2) SCV_{A,1} + \rho_1^2 SCV_{S,1}, \; P_{1,2} = \frac{\sum_{r=2}^{3} \zeta_r}{\lambda_1}.$$

Station 2 has mean contact time and SCV

$$E(S_2) = \frac{1}{\lambda_2} \sum_{r=2}^{3} \zeta_r E(S_{r,2}),$$

$$SCV_{S,2} = \frac{1}{\lambda_2 E^2(S_2)} \sum_{r=2}^{3} \zeta_r E^2\,(S_{r,2})(SCV_{S,r,2} + 1) - 1$$

The arrival process at station 3 has SCV

$$SCV_{A,3} = w_3(Q_{2,3} SCV_{2,3} + Q_{1,3} SCV_{1,3}) + 1 - w_3, \text{ with}$$

$$w_3 = \frac{1}{1 + 4(1-\rho_3)^2(v_3 - 1)}, \; v_3 = \frac{1}{Q_{2,3}^2 + Q_{1,3}^2},$$

$$Q_{2,3} = \sum_{r=2}^{3} \frac{(1 - da_r)\zeta_r}{\lambda_3},$$

$$Q_{1,3} = \frac{\sum_{r=4}^{4+3d} (1 - da_r)\zeta_4}{\lambda_3}, \; SCV_{1,3} = P_{1,3} SCV_{D,1} + 1 - P_{1,3},$$

$$P_{1,3} = \frac{\sum_{r=4}^{4+3d} (1 - da_r)\zeta_4}{\lambda_1},$$

$$SCV_{2,3} = (1-d) SCV_{D,2} + d(P_{2,3} SCV_{D,2} + 1 - P_{2,3}),$$

$$P_{2,3} = \sum_{r=2}^{3} \frac{(1 - da_r)\zeta_r}{\lambda_2},$$

$$SCV_{D,2} = 1 + (1-\rho_2^2)(SCV_{A,2} - 1) + \frac{\rho_2^2}{\sqrt{s_2}}(SCV_{S,2} - 1),$$

where $SCV_{2,3}$ is the SCV of the patient flow from station 2 to station 3, $SCV_{1,3}$ the SCV of the patient flow from station 1 to station 3, and $SCV_{D,2}$ is the SCV of the departure process at station 2. $P_{1,3}$ is the portion of aggregated flow out of station 1 to station 3, and $P_{2,3}$ is the portion of aggregated flow out of station 2 to station 3.

Station 3 has mean contact time and SCV

$$E(S_3) = \frac{1}{\lambda_3} \sum_{r=2}^{4} (1 - da_r)\zeta_r E(S_{r,3}) + d \sum_{r=5}^{7} \zeta_r E(S_{r,3})$$

$$SCV_{S,3} = \frac{1}{\lambda_3 E^2(S_3)} \left(\sum_{r=2}^{4} (1 - da_r)\zeta_r E^2(S_{r,3})(SCV_{S,r,3} + 1) + \sum_{r=5}^{7} \zeta_r E^2(S_{r,3})(SCV_{S,r,3} + 1) \right) - 1$$

Step 3: Performance Measures per Patient Class

We are interested in the waiting times for patients per station and the utilization rates per employee at each station. The latter is given by the aggregated utilization rates derived in step 1, whereas the mean waiting times are obtained by using the SCVs and mean service times calculated in step 2. The mean waiting time $E(W_{Q,i})$ at the 3 service stations is equal for all patient classes.

$$E(W_{Q,1}) = \frac{SCV_{A,1} + SCV_{S,1}}{2} \frac{\rho_1}{1-\rho_1} \frac{E(S_1)}{e_1},$$

$$E(W_{Q,i}) = \frac{SCV_{A,i} + SCV_{S,i}}{2} E(W_{Q,i(M/M/c)}),$$

$$\text{where } E(W_{Q,i(M/M/c)}) = \frac{(s_i\rho_i)^{s_i}}{s_i! G_i} \frac{1}{(1-\rho_i)^2} \frac{E(S_i)}{s_i},$$

$$G_i = \sum_{n=0}^{s_i - 1} \frac{(s_i\rho_i)^n}{n!} + \frac{(s_i\rho_i)^{s_i}}{(1-\rho_i)s_i!} \text{ for } i = 2,3.$$

Patient length of stay for each patient class can now be calculated by adding the mean waiting and length of stay of all care stations the patient calls at on his or her visit to the PAC.

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