Using computer simulation to reduce access time for outpatient departments

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Aim: To develop general applicable models for analysing the capacity needed in appointment-based hospital facilities.

Method: A fairly simple analytical queuing model was used to obtain rapid global insight into the capacity needed to meet the norm of seeing 95% of all new patients within 2 weeks. For more detailed analysis, a simulation model was developed that could handle daily variations in demand and capacity schedules. The capacity needed to eliminate backlogs and the capacity needed to keep access time within 2 weeks was calculated. Both models were applied to two outpatient departments (neurology and gynaecology) at the Academic Medical Center in Amsterdam, the Netherlands. Model results for neurology were implemented.

Results: For neurology, to eliminate the 6-week backlog, 26 extra consultations per week were needed over 2 months. A permanent increase of 2-weekly consultations was required to keep access time within 2 weeks. Evaluation after implementation showed the improvements the model had predicted. The gynaecology department had sufficient capacity. With the simulation, it was calculated that the same service level could be achieved with 14% less capacity. Thus the models supported decisions made for departments with shortages of capacity as well as those for departments with adequate capacity.

Conclusion: The analytical model provided quick insight into the extra capacity needed for the neurology department. The added value of the simulation model was the possibility of taking into account variations in demand for different weekdays and a realistic schedule for doctors' consultations. General applicability of the models was shown by applying both models to the gynaecology department.

Improving organisational aspects of care such as access and waiting times is an important and ongoing activity in many healthcare facilities. "Advanced Access"¹ and "Sneller Beter"² (in the Netherlands)² are examples of programmes adopted by hospitals to improve the quality and organisation of care. The Academic Medical Center (AMC) in Amsterdam, the Netherlands, started a programme with the aim of improving the logistic aspects of their outpatient departments.

In this paper we report on the main results from two departments: neurology and gynaecology. Our analyses revealed that the main bottleneck in these departments was access time for new patients. The percentage of consultation requests for new patients amounted to about 42% of all consultations for neurology as well as for gynaecology. We focused on two aspects of access time: the capacity needed to meet the norm of seeing 95% of all new patients within 2 weeks, and ways to eliminate backlogs. We used operations research techniques to analyse capacity and demand and also to investigate how to improve access time. An initial global analysis was done using analytical waiting-time models. For a more detailed analysis, we developed a simulation model that incorporated several specific characteristics of the processes.

Several simulation studies for outpatient departments have been published. However, all of these have focused on internal hospital processes, for example, the time patients are registered to their discharge.^{3–8} In these studies, outcome measures were patient waiting time between different steps of the process and idle time for doctors and other personnel. However, these studies did not deal with access time. Also, to our surprise, we did not find any articles that described using simulation models to analyse access time, and few articles have reported on implementing simulation results.⁹ In this article we describe a generally applicable computer simulation model to analyse access times for hospital services and to investigate the capacity

needed to reduce these access times. We give both the analytical model and the simulation model, including the results following implementation in two outpatient departments of the AMC. The questions that guided our study were:

- To what extent are analytical models appropriate and when is simulation essential for more insight?
- Is it possible to generalise the models and results to other departments?

METHOD

Our analysis aimed to investigate the relationship between new patient demand and the capacity of doctors needed for initial consultations in an outpatient department. Demand is defined as the number of appointments requested. Due to fluctuations in both demand and available capacity, it is not easy to manage access time. It is essential to obtain insights into how capacity and demand affect access time and what capacity is needed to guarantee a certain service level with respect to patient access time. We were able to deal with this problem using operations research techniques.

We considered the neurology department's system, which uses appointment-based scheduling only with no walk-ins. In the schedule, dedicated capacity is reserved for new patients, which does not interfere with other demand streams. For the first visit, a fixed time is reserved for every patient. A patient's access time is defined as the time the patient has to wait between making the appointment and the first visit. This process is a typical example of a single queuing model, with one waiting row (patients with appointments waiting for access) and one service station (the outpatient department). Our method consisted of two phases: first, a global analysis and second, a detailed study with a simulation model.

Table 1 Input and results from the analytical model for the neurology outpatient department

	2004	2005	2005 (same access time as in 2004)	2005 (94% utilisation)
Mean demand per working day	7.70	7.90	7.90	7.90
Mean capacity per working day (number of consultations)	8.53	7.56	8.75	8.4
Utilisation (%)	90.3	104.5	90.3	94.0
Mean access time (working days)	0.5	Permanently increasing	0.5	0.9
Mean length of queue (number of patients)	4.2	Permanently increasing	4.2	7.4

We used some basic results from what is known as an $M/D/1$ queuing model to obtain a global indication of the following performance measures: utilisation (that is, total demand divided by available capacity in a certain period), average access time, and average queue length (see for example, Tijms¹⁰ and Ross¹¹). This model assumes that patient requests arrive at random and independently of each other; it is said that the arrival process is “memory-less”, and is indicated by “M” in the notation. The “D” in the notation stands for a fixed, deterministic duration of the consultation for every patient. The capacity in a queuing model is usually expressed by the number of servers, for example c doctors in an $M/D/c$ model. Because the number of doctors working during office hours can vary, capacity can vary. Therefore, we expressed capacity as the number of available consultations and assumed hereby that only one doctor at a time would be available. This meant that a week was equal to a sequence of consultations spread over the week. By doing this, we neglected the effect of having parallel available consultations, but this would have mainly affected the waiting time on the day of the visit itself rather than access time, which is expressed in number of days. Although in the simulation model we did not need to make this simplification, the analytical model was meant to quickly provide an initial, global insight.

As fewer simplifications have to be made, a simulation model can be used to obtain more realistic and detailed results. A clear distinction can be made between demand on specific working days. In addition, in a simulation model the complete weekly schedule of office hours can be used as input. This schedule describes the total number of reserved consultations per working day and the number of doctors who would be working per consultation. Another advantage of a simulation model is the possibility of visualising the results over time. This provides insight into the results and makes it easier to communicate with the doctors, which proved to be of great importance in the later implementation phase of the project. We developed a

discrete event simulation model, which implies that the state of the system only changes due to certain events, such as a request for a consultation or completing a consultation, which occur at discrete moments in time (see for example, Law and Kelton¹²).

To validate both models, we compared model access times with values measured in the department. The results obtained from the analytical model indicated the performance when using the actual capacity. It was also possible to make a rough estimate of how much capacity was necessary to satisfy a certain service level. In addition, utilisation indicated how long it would take to eliminate the actual delay in appointments (the backlog). The simulation model also provided more specific information, such as a 95% percentile: this gives the maximum access time for 95% of the patients in the outpatient department. When there was a backlog, the simulation model could determine how much and for how long temporary capacity would be needed to eliminate the backlog and achieve the required service level. Our goal was to create models for the neurology outpatient department as well as generic models. To demonstrate this, we applied the two models to the gynaecology outpatient department.

RESULTS

Our first objective was to analyse the capacity of and demand for office hours reserved for new patients at the neurology outpatient department. This department used appointment-based scheduling, with 105 min being reserved for each new patient. Using the AMC's regular planning system (XCare by McKesson), we gathered information on demand and obtained the available (and achieved) capacity for first consultations of new patients from the department itself. We included all new patients in our analysis, except for those who needed urgent consultation. The two models were applied to the data from 2004 and 2005. Table 1 shows the results of the analytical model. Using the historical data of 2004, a utilisation of 90% was obtained. The access time calculated with the analytical

Figure 1 Access time at the neurology outpatient department according to capacity, demand, and backlog in 2005 with a 60% increase in capacity over a 2-month period, obtained by simulation.

Figure 2 Access time at the neurology outpatient department achieved with permanent and temporary extra capacity in 2005, obtained by simulation.

model was 0.5 working days. Because actual access time was not measured in 2004, we were not able to compare our results with what had been achieved. However, access time *was* measured in 2005; in August 2005, it was 28.1 working days. This had been expected, because in 2005 utilisation was 104%, which meant that access time was increasing.

Two reasons for the sharp contrast between access times in 2004 and 2005 were the reduced capacity and increased demand in 2005. To have the same access time as in 2004, the average capacity should have been 8.75 per day. The simulation model confirmed the analytical results: in 2004, capacity was enough to meet the demand; in 2005 utilisation was 100% and access time increased.

After validating the models, we examined the problem of increasing access time in 2005. Using the simulation model we calculated that the backlog could be eliminated with an extra weekly capacity of 26 consultations over 2 months (fig 1). This meant a temporarily increase in capacity of more than 60%. Figure 1 also shows that following this 2-month period, access time would start increasing again when no additional capacity is used on a permanent basis.

To keep access time within 2 weeks, extra capacity of two consultations a week was needed. Implementation of permanent extra capacity should lead to a utilisation of 94% and mean access time would eventually be 1.83 working days with a 95% percentile of 5.62 working days (see also fig 2) which achieved the project's goal.

Using the analytical model, calculation of this situation (utilisation of 94%) led to a capacity of 42 consultations a week and average access time of 0.9 days (see right-hand column in table 1). The difference between the simulation and the analytical model was because less detail was included in the latter, as discussed above.

Starting in January 2006, the department added one extra doctor with a capacity of 25 consultations weekly, one fewer than the number calculated. Unfortunately, it was not possible to maintain this extra capacity until the backlog had been completely eliminated. Figure 3 shows the performance as measured after the implementation.

Although the average access time was less than 10 days, the 95% percentile was not. The difference between the model's results and the actual situation could be attributed to an unexpected increase in demand. The permanent extra capacity was created in August 2006. In the meantime the backlog increased somewhat, so at the start there was an average access time of slightly more than 10 working days. We are still having discussions with the outpatient department on adding some extra temporary capacity to eliminate the last part of the backlog.

Gynaecology outpatient department

The same analysis, using the same models as described above, was carried out in the gynaecology outpatient department. Using the data from 2004, a utilisation of 96% was achieved.

Figure 3 Mean access time and 95% percentile measured at the outpatient department between February and June 2006.

Table 2 Input and results from the analytical model for the gynaecology outpatient department

	2004	2005
Mean demand per working day	10.9	9.8
Mean capacity per working day (number of consultations)	11.3	11.9
Utilisation (%)	96	82
Mean access time (working days)	1.2	0.2
Mean length of queue (number of patients)	13.1	1.9

Despite this high percentage, according to the model the mean access time was only 1.2 working days. In 2005 the demand dropped to 9.8 consultations per working day (table 2). However, capacity increased by an average of 0.6 extra consultations per working day, which resulted in a utilisation of 82% and a mean access time of 0.2 working days. We found the same average access time using the simulation model, and the 95% percentile was less than 10 working days. In 2005 the access time was even lower (see fig 4). In contrast with the neurology outpatient department, the gynaecology department had enough capacity to fulfil the 95% percentile within the norm of 10 working days. With use of the simulation model, we found that the gynaecology outpatient department could reduce capacity to 86% of the current capacity and still fulfil the service level of 95%. The utilisation rate would then be 89%.

DISCUSSION

We have presented a method, using two models, to analyse access time and to investigate the capacity needed to eliminate backlog, taking into account fluctuations in demand. We applied both models to two outpatient departments. The results of the analytical model corresponded broadly with the results of the simulation model. The analytical model seemed to be useful to gain initial insight into the capacity needed and can be used to obtain insight into the extra capacity needed to keep average access times within the established norms.

Variations in the process can be taken into account in more detail in a simulation model. With the simulation model, it was possible to incorporate different timetables on different working days and varying demand per working day. Another benefit of the simulation model is the possibility of presenting the results as more attractive graphic illustrations. This helped us—especially

in our communications with the neurology department—to convince the department of the need to add permanent capacity.

In contrast with most of the literature, we calculated possibilities for reducing access time and implemented the model results in practice.^{3 6 9} For the neurology outpatient department we added temporary extra capacity to reduce the backlog and permanent extra capacity to keep access time within 2 weeks. This added capacity was not at the expense of capacity for other patient streams. Although the average access time turned out to be less than 10 days, the 95% percentile did not. The difference between the model results and the actual situation could be attributed to an unexpected increase in demand and to the early termination of the temporary extra capacity. However, in spite of some explainable differences between model results and measurements following application, we are convinced the model was a useful guide for capacity analyses.

There was no backlog for the gynaecology outpatient department. Using the simulation model, we analysed the possibility of reducing capacity while keeping 95% of all new appointments to within 2 weeks. The model showed that 86% of the current capacity should be enough to fulfil the service level of 95%. So, the model can be used to analyse both:

- the extra temporary and permanent capacity needed to eliminate backlog and keep access time within stated norms for departments with capacity shortages;
- the improvements in efficiency that can be achieved in a department with sufficient capacity.

By applying both models to the gynaecology outpatient department, we have shown that the models are generic. Because input for the model is relatively simple, this also contributes to the general applicability in other hospitals. It was indeed easy to acquire the essential data and the analyses were straightforward. The results and recommendations for gynaecology were quite different from those for neurology. So, the same model could be applied in spite of the different capacity issues of the two departments.

One limitation of this model is the use of only one fixed consultation duration. When simulating appointment systems, it is not necessary to take into account variability in duration of a consultation because appointments always have a predefined duration. A slightly adjusted model is needed to deal with different durations for distinct patient groups. This will be a relatively easy adjustment for both the simulation tool and the analytical model. These models provide us with useful applications for analysing

Figure 4 Access time in the gynaecology outpatient department according to capacity and demand in 2005, obtained by simulation.

capacity. In contrast with most literature, we did not analyse a chain of subsequent steps in a care process but one specific and very important part: access time.^{6 7 13} We were able to calculate the capacity needed for a steady state as well as to eliminate backlogs for all kinds of appointment-based hospital facilities. We will use these models in future projects to help departments gain insight into the possibilities for meeting fluctuating demand within the stated norms for access time.

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