RESEARCH PAPER

Evaluation of Booking Systems for Elective Surgery Using Simulation Experiments

Simulations expérimentales pour évaluer les systèmes de rendez-vous pour les chirurgies non urgentes

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Abstract

Objective: This study compared two methods of booking elective surgery – booking from wait lists and pre-booking surgery dates at the time of decision to operate – in terms of cancellations of elective procedures and time to surgery.
Methods: The authors conducted simulation experiments with group randomized design, in which the unit of allocation was the hospital and the units of analysis were both the hospital and the patient.
Results: In the case of pre-booking, cancellation of high-priority elective procedures was only one-third as likely as it was in the case of booking from wait lists (odds ratio 0.35; 95% confidence interval 0.18–0.68). After adjustment for hospital and patient factors, the weekly likelihood that patients on the wait list had their operation was about 20% higher for medium-priority procedures (OR 1.21; CI 1.18–1.24) after pre-booking surgery dates.
Conclusion: The findings suggest that redesigning booking processes may improve the performance of surgical services.

Résumé

Objectif : Dans cette étude, on a comparé deux méthodes de planification des rendez-vous pour les opérations chirurgicales non urgentes – les listes d'attentes et les rendez-vous déterminés au moment de la décision de procéder à l'intervention chirurgicale – en fonction des annulations d'intervention et du temps d'attente pour la chirurgie.
Méthodes : Les auteurs ont effectué des simulations à l'aide de plans d'expérience aléatoire dans lesquels l'unité de répartition était l'hôpital et les unités d'analyse étaient l'hôpital et le patient.
Résultats : Dans le cas des dates pré-déterminées, le risque d'annulation d'une intervention désignée comme hautement prioritaire équivalait au tiers du risque d'annulation dans le cas des rendez-vous accordés selon les listes d'attente (rapport de cotes 0,35; 95 % intervalle de confiance, 0,18–0,68). Après ajustement des facteurs « hôpital » et « patient », la probabilité hebdomadaire qu'un patient sur la liste d'attente subisse l'intervention était environ 20 % plus élevée pour les interventions de priorité moyenne (1,21; 1,18–1,24), après la date d'intervention pré-déterminée.
Conclusion : Les résultats indiquent qu'une nouvelle conception des processus de rendez-vous pourrait améliorer le rendement des services de chirurgie.

Booked admissions have been suggested as an alternative method for scheduling elective surgery (Ham et al. 2003). Instead of keeping patients on wait lists until there is an available slot in the operating room, consulting surgeons pre-book the surgery date at the time of their decision to operate (McLeod et al. 2003). To clarify the impacts of pre-booking on access to care, we analyzed data from simulation experiments using a framework of intervention study (Sobolev and Kuramoto 2005). The process of scheduling surgery consists of allocating operating time to various surgical services (Blake et al. 2002), assigning blocks of operating time to surgeons (Blake and Donald 2002) and booking patients into the operating room slots of their respective surgeons (Dexter and Traub 2002). The booking determines the day of hospital admission when appropriate patient care is available (Hamilton and Breslawski 1994). It takes account of the availability of hospital resources and specialists' schedules.

In this analysis, we compared pre-booking and booking from wait lists in terms of cancellations originating with the hospital and time to surgery in the context of cardiac surgical care. Because booking surgery involves complex decision-making at the level of the hospital, we applied a cluster randomized design (Donner and Klar 1994) in which the unit of randomization was the hospital and the units of analysis were both the hospital and the individual patient (Ukoumunne et al. 1999). At the hospital level, the outcome was cancellation of one or more elective procedures with high priority from the final operating room schedule. At the patient level, the outcome was time between registration on a wait list and the operation.

We studied a setting in which weekly availability of surgeons for operations depended on their schedules for consultations, planned operations, on-call duties and vacations. Weekly operating room slots were divided between urgent and elective procedures and more urgent procedures might cause the cancellation of planned operations. Comparisons at the hospital level were used to assess whether pre-booking decreased the proportion of hospitals in which high-priority procedures were cancelled. Comparisons at the patient level were used to assess whether pre-booking improved patients' access to elective procedures.

In this paper, we applied the results of mapping cardiac services at a major teaching hospital in Canada, where the booked admissions program has long been in use (Sobolev et al. 2008).

Methods

Modelled peri-operative activities

We simulated the progress of individual patients through care steps using a discrete event model. The Appendix (available online @ *http://www.longwoods.com/product.php?productid=19896*) to this paper contains a description of the simulation approach, underlying assumptions and the values of the model parameters.

Each simulation run generated a series of updates in individual patient records in response to events produced by the modelled peri-operative activities (Table 1).

The patient records contained the occurrence and timing of simulated events, such as outpatient consultation, registration on the wait list and the operation itself, as well as cancellation or pre-operative death, if such occurred.

TABLE 1. Clinical and managerial activities included in the model

Activity	Function
Referral of elective patients for outpatient assessment	Patients presenting with symptoms are sent for consultation with surgeon in outpatient clinic
Registration of elective patients on appointment list	Details of referred patients are registered
Scheduling of elective patients for appointment	Time and duration of appointments are determined
Outpatient appointments for elective patients	Indication for operation is assessed (by surgeon)
Registration of elective patients on surgical wait list	Details of patients who require and decide to undergo the operation are registered
Pre-booking of elective patients for operation	Projected dates of operations within the upcoming 36-week period are determined after consultations (pre-booking)
Referral of patients requiring urgent specialist assessment	Patients requiring urgent assessment after angiography are referred (by cardiologist)
In-hospital assessment of patients requiring urgent treatment	Suitability of patients for admission to hospital as inpatients is determined (by on-call surgeon)
Registration of inpatients in surgical queue	Details are registered for patients who must undergo the operation and who are admitted directly to hospital
Scheduling of operating time	Inpatients and elective patients waiting for operation are identified, and hospital resources are reserved
Updating of operating room time	Final theatre schedule is created
Arrival of emergency patients	Patients requiring emergency operation are sent for procedure
Cancellation of scheduled operations by emergency arrivals	Emergency patients requiring immediate operation replace previously scheduled patients in the operating room schedule
Cancellation of scheduled operations by inpatients	Inpatients requiring surgery replace previously scheduled patients in the operating room schedule
Rescheduling of cancelled operations	Patients who are still waiting for operation after surgery was cancelled are identified, and hospital resources are reserved
Surgical procedures	Operation is performed, during which time patients have access to operating room resources
Discharge from hospital	Patients are prepared for post-operative care at home or in rehabilitation or community facilities

TABLE 1. Continued

Audit of wait lists	Names of patients who die while waiting for the operation are removed from surgical waiting lists
Allocation of appointment and theatre slots to surgeons	Appointment and theatre slots are allocated to surgeons according to duty rotation and vacation schedule for upcoming 18-week period

We modelled three care paths following angiography that patients with established coronary artery disease are likely to experience according to initial presentation and subsequent decisions leading to surgery: elective, inpatient and emergency, as reported elsewhere (Sobolev et al. 2006). The elective path applies to patients for whom surgical consultation and subsequent operation can be safely delayed. The inpatient path applies to patients admitted to hospital from the catheterization laboratory when urgent surgical assessment is necessary. The emergency path applies to patients requiring immediate surgical intervention. Patients referred for outpatient consultation are kept on the appointment list with a designated priority (high or low) until an opening for a clinic consultation becomes available. In the case of individual appointment lists, consultations are scheduled with the surgeon named in the referral. In the case of pooled appointment lists, consultations are scheduled with the first available surgeon.

After the consultation, the office of the consulting surgeon registers on the surgeon's wait list patients who require coronary revascularization, designating the required procedure as high-, medium- or low-priority, according to affected coronary anatomy and symptoms. The hospital's booking office books patients into operating room slots allocated to the consulting surgeon according to their priority and date of registration. In the case of wait list booking, booking is attempted weekly until a free slot is found. Because of prioritization, newly registered cases with higher priority delay scheduling of cases with lower priority already on the lists. In the case of pre-booking, cases are pre-booked for the next available slot for the upcoming 36-week period.

A draft schedule for the operating rooms is generated every Friday. In the case of wait list booking, the draft schedule lists procedures that have been booked from the wait lists and those booked for inpatients already waiting in hospital. In the case of pre-booking, the draft schedule lists procedures for pre-booked cases and for inpatients waiting in hospital. The schedule is finalized the following Monday and may be subsequently changed to reflect the arrival of inpatients and emergency patients. The availability of three surgeons for operations and consultations is coordinated through their weekly schedules such that, in any given week, one surgeon is on call (assessing inpatients and performing urgent operations), one performs planned operations and one conducts outpatient consultation. During weeks in which one surgeon is on vacation, the two remaining surgeons alternate call and planned duties, and no consultations are scheduled.

Experimental design

The experiment consisted of runs of the model with different algorithms for booking consultations and operations, and four additional two-level factors likely to influence model performance (method of allocating operating room slots, size of queues for outpatient consultation, elective surgery and inpatient surgery at the start of the simulation). Each run generated a group, or cluster, of patients served in a modelled hospital, with the cluster size being determined by the arrival and service rates, and by simulation time. We evaluated performance over a period of 108 weeks, which corresponded to three booking horizons of 36 weeks, or six 18-week cycles, of allocation of clinic and operating time to three surgeons.

As waiting times in a given hospital may be correlated, we used a cluster randomized design for intervention studies with a simulation run as the allocation unit (Sobolev and Kuramoto 2005). Before allocation to intervention groups, a random combination of the four factors was specified for each run (Cooper et al. 2002). The runs were then randomized to the four intervention groups: (1) individual appointment lists with pre-booking, (2) individual appointment lists with booking from wait lists, (3) pooled appointment lists with pre-booking and (4) pooled appointment lists with booking from wait lists.

In an intervention study, the sample size needs to be such that the evaluation is able to detect the anticipated effect of the intervention with a high probability. We estimated that 64 runs (i.e., modelled hospitals) per intervention group would have 90% power to detect a 15% difference in the proportion of runs that have cancellations of high-priority elective procedures for inferences at the hospital level in a two-sided 5% significance test (Kerry and Bland 1998a).

Dependence between outcomes in each hospital requires adjustment for within-hospital correlation at the design and analysis stage. We estimated that 256 runs would have 90% power to detect a 15% difference in the weekly operation rate between groups of patients in a two-sided 5% significance test (Kerry and Bland 1998b). Therefore, we had a full factorial 2^6 design with four replicates (26 x 4 = 104) that allowed assessment of all main effects (Box et al. 1978). In calculating the sample size for inferences at the patient level, we estimated an average of 1,730 patient-weeks per simulation run and assumed a coefficient of variation for rates to be 0.25 (Donner and Klar 2000).

Statistical analysis

The outcomes for the intervention groups were compared at the level of the hospital, with application of regression methods to the hospital proportions, and at the level of the individual, according to formulas that were adjusted for within-hospital correlation. The odds ratios (ORs) derived from logistic regressions measured the effect of pre-booking on the proportion of hospitals in which one or more elective procedures with high priority were cancelled (Hosmer and Lemeshow 1989). The ORs derived from discrete time survival regressions measured the effect of pre-booking on the weekly proportion of patients on the surgical wait lists who underwent the operation (Sobolev and Kuramoto, 2008). We used multivariate models to control for hospital and patient factors. For inferences at the hospital level, in addition to an indicator variable for the method of booking surgery, we entered indicator variables for the method of scheduling consultations (individual or pooled) and the method of allocating operating room slots (weekly or daily split between elective and urgent procedures), as well as indicator variables for the initial size of the queues for outpatient consultations (16 or 48), elective procedure (21 or 42) and inpatient procedure (0 or 16). For inferences at the patient level, we entered an additional indicator variable for the referral period during the simulation (weeks 1 to 54 or weeks 55 to 108) and a continuous variable for clearance time at registration (see Table 2). In the discrete time survival models, we also controlled for the weekly number of inpatient and emergency admissions, weeks on the wait list and within-hospital correlation (Sobolev et al. 2004).

TABLE 2. Priority, referral period and clearance time at registration on surgical wait list (as percentage of patients in each intervention group)

	Intervention group*			
	1 (n=49,747)	**2 (n=49,919)**	**3 (n=50,632)**	**4 (n=49,957)**
Priority group				
High	7.2	7.4	7.2	7.1
Medium	70.5	70.3	70.6	70.6
Low	22.3	22.4	22.2	22.3
Referral period during simulation				
1 to 54 weeks	52.9	53.0	52.1	52.3
55 to 108 weeks	47.1	47.0	47.9	47.7
Clearance time†				
Less than half a week	79.4	68.1	64.5	53.7
Half week to 1 week	20.0	26.8	33.6	36.8
More than 1 week	0.6	5.1	1.9	9.5

* (1) individual appointment lists, pre-booking; (2) individual appointment lists, booking from wait lists; (3) pooled appointment lists, pre-booking; (4) pooled appointment lists, booking from wait lists.
† Hypothetical time within which the wait list could be cleared at the maximum weekly service capacity if there were no new arrivals.

Results

The simulation generated 211,172 referrals for elective procedures, 196,275 inpatient and 15,007 emergency cases during 108 weeks in 256 hospitals. At registration on the surgical wait lists, about 70% of the cases had medium priority, and clearance time was one week or less for 98% of the elective procedures scheduled by pre-booking and for 92% of those booked through wait lists (Table 2). Some scheduled procedures were cancelled (9%); others did not occur by the time the study ended (1%).

The proportion of elective procedures with high priority that took place within one week of the treatment decision was 96.4% for pre-booking and 88.9% for wait list booking; 3.2% and 5.6%, respectively, of such procedures were cancelled from the final operating room schedule. The proportion of hospitals in which elective procedures with high priority had cancellations was 74.3% for pre-booking and 88.6% for wait list booking (Table 3). After adjustment for hospital factors, cancellation of high-priority elective procedures with pre-booking was only one-third as likely as for booking from wait lists (OR 0.35, 95% CI 0.18–0.68) (Table 3).

TABLE 3. Cancellation of high-priority procedures according to method of booking surgery*

	Proportion (95% CI)	**Odds Ratio† (95% CI)**
Wait list booking	88.6 (83.3, 93.8)	1.0
Pre-booking	74.3 (67.0, 81.5)	0.35 (0.18–0.68)

CI = confidence interval.
* Presented as proportions of hospitals and corresponding odds ratios (with 95% CI) in which at least one elective procedure with high priority was cancelled after the final operating theatre schedule was created.
† Adjusted for initial queue size at time of consultation, size of elective and urgent queues at registration on wait list, method of scheduling consultation and method of allocating theatre slots.

For patients needing medium-priority procedures, the average number of operations per week was 45.5 and 38.1 per 100 patients remaining on wait lists for pre-booking and wait list booking, respectively (Table 4); 9.5% and 10.2% of scheduled procedures, respectively, were cancelled from the final operating room schedule. After adjustment for hospital and patient factors, the weekly odds that a medium-priority patient on the wait list underwent the operation were 20% higher for pre-booking (OR 1.21, CI 1.18, 1.24) (Table 4).

For patients needing low-priority procedures, the average number of operations per week was 31.4 and 21.2 per 100 patients remaining on wait lists for pre-booking and wait list booking, respectively (Table 4); 5.1% and 8.1% of scheduled procedures, respectively, were cancelled from the final operating room schedule. After adjustment for hospital and patient factors, the weekly odds that a patient on the wait list would undergo the operation were more than two times higher for pre-booking (OR 2.13, CI 2.03, 2.22) (Table 4).

TABLE 4. Weekly proportion of patients on wait lists who underwent the operation with medium and low priority according to method of booking surgery*

	Medium priority		Low priority	
	No. of procedures (95% CI)	**Odds Ratio†‡ (95% CI)**	**No. of procedures (95% CI)**	**Odds Ratio†§ (95% CI)**
Wait list booking	38.1 (37.8, 38.4)	1.00	21.2 (20.9, 21.5)	1.00
Pre-booking	45.5 (45.2, 45.9)	1.21 (1.18, 1.24)	31.4 (30.9, 31.8)	2.13 (2.03, 2.22)

CI = confidence interval.
* Presented as the average number of procedures per week per 100 patients remaining on wait lists.
† Adjusted for initial queue size at time of consultation, size of elective and urgent queues at registration on wait list, method of scheduling consultation, method of allocating theatre slots, period of referral, emergency and urgent admissions, clearance time at registration and week from registration.
‡ Adjusted for exchangeable correlation within hospitals (0.0012).
§ Adjusted for exchangeable correlation within hospitals (0.0033).

Discussion and Conclusions

The total length of post-referral time for patients undergoing surgery is the sum of the time from referral to consultation and the time from consultation to surgery. However, the implications of different appointments and booking systems for access to care are poorly understood. In this study, we compared booking operations from wait lists and pre-booking surgery dates at the time of decision to operate by means of simulation experiments that allowed inferences at the levels of both hospital and patient (Ukoumunne et al. 1999).

We found that cancellations of elective procedures with high priority were less likely after pre-booking surgery dates and that within each priority group a larger proportion of patients on wait lists were likely to undergo an operation each week if procedures were pre-booked. Given that the weekly proportion of operations in relation to the size of the wait lists estimates the conditional probability of the operation taking place while waiting, the latter observation means shorter times to elective surgery (Sobolev et al. 2006). Higher cancellation rates after wait list booking may be attributable to a higher proportion of patients who need elective surgery being scheduled in the on-call slot with this method of booking, because of prioritization. Therefore, these patients are at higher risk of cancellation caused by the arrival of emergency patients or inpatients. Shorter time to surgery after pre-booking may be a result of scheduling cases in the order of booking requests; in contrast, with wait list booking, newly registered cases with higher priority delay scheduling of cases with lower priority already on the lists.

Others have used simulation experiments to explore the implications of different booking systems (Tuft and Gallivan, 2001). Contrary to our results, they suggested that an increase in cancellations of scheduled cases may be an unintended consequence of pre-booking. However, their analysis ignored factors relevant to the underlying peri-operative process, including the weekly availability of specialists. The use of simulations for evaluating healthcare policy is based on two premises: first, that simulated individual care paths realistically represent the delivery of health services to a patient population and, second, that simulation produces care paths that are likely under the policy in question (Sobolev and Kuramoto 2005). Therefore, assessing the impacts of alternative booking systems should account for interaction between specialists' and hospitals' schedules. One previous analysis also did not account for interaction between appointments and booking systems (Gallivan et al. 2002), although the evidence suggested that the appointment system may influence the time to surgery (Vasilakis et al. 2007). Increasingly, health services research seeks to evaluate suggested changes in hospital care delivery (Hall et al. 2006). When possible, intervention studies are used to compare existing and proposed alternatives in management and policy. When organizational interventions are not feasible because of ethical, economic or other reasons, computer simulation provides an alternative method to quantify the effects of proposed changes in healthcare delivery. The results of our simulation experiments may have implications for policies on managing access to elective surgery in a network of hospitals. If the wait list size and the weekly number of inpatients vary significantly from hospital to hospital in a region, policy makers may consider redistribution of cases across hospitals. That would require a centrally managed pre-booking system. Our findings suggest that redesigning booking processes may improve the performance of surgical services.

In this study, we evaluated two methods of booking elective surgery using specifications of peri-operative activities that constitute the process of cardiac surgical care. Because these managerial and clinical activities are generic across surgical services (Table 1), the results of our evaluation may be applicable to other settings in which wait lists are used to manage access to surgical procedures in hospital. Indeed, by varying other factors that are likely to influence service performance, such as method of allocating operating room slots and method of scheduling clinic appointments, we were able to delineate the independent effect of booking methods. In addition, the delivery of surgical services was simulated over six cycles of allocation of clinic and operating time to maximize variation in the dependent variables and, therefore, to increase the precision of our estimates. However, some limitations of our model should be recognized in assessing our results. For example, although we were able to account for availability of surgeons for operations, fluctuations in availability of hospital staff and intensive care beds were not considered in the model because of lack of information about policies for cancellation due to staff shortage and bed blockage.

Further research is required to explore the implications of booking systems on patient flow, specifically, the impact of the ratio of slots allocated for urgent and elective procedures on time to surgery for patients needing procedures urgently; the implications of policies for postponement or cancellation of elective procedures and re-scheduling cancelled surgeries in relation to time to surgery; and the effects of the order of elective procedures on a given day, patient segmentation, the partitioning of inpatient and outpatient facilities, and dedicated operating rooms. Other remaining questions include whether successful management solutions developed in one hospital can be transferred to other institutions.

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Appendix: The Simulation Model

Simulation approach

We applied Statecharts formalism to describe the progress of individual patients through surgical care as a series of asynchronous updates in patient records generated in reaction to events produced by parallel finite state machines representing concurrent clinical and managerial activities (Gruer et al. 1998). The specifications of perioperative activities were based on the process of cardiac surgical care at a tertiary care hospital in British Columbia, Canada (Vasilakis et al. 2007). We used the Statecharts language to define detailed functional and behavioural specifications of states and transitions within each activity of care delivery (Sobolev et al. 2008). This approach allowed us to include realistic features of scheduling consultations and booking admissions, which made the simulation results applicable to other surgical services. For example, using Statecharts notions of parallelism and event broadcasting, we represented the availability of surgeons for consultations, scheduled operations and on-call duties by developing one statechart for describing the rotation of duties and vacation schedules and another for describing the allocation of clinic and operating room slots to surgeons according to their weekly availability.

Underlying assumptions

In constructing the simulation model, we made the following simplifying assumptions.

- For each simulation week, the random numbers of referrals for consultations and the random numbers of emergency patients and inpatients were drawn from Poisson distributions to allow for fluctuations in demand.
- Referrals can have high or low priority for surgical consultation. Those with high priority are scheduled before those with low priority; referrals with the same priority are scheduled by referral time.
- Sixteen consultation appointments are available each week, and all patients attend their appointments.
- Seven operating room slots for elective surgery and eight for urgent procedures are available each week. Two methods for allocation of operating room slots over weekdays were studied: weekly and daily, split between elective and urgent procedures.

- In pre-booking, elective cases with high and medium priority are eligible for scheduling in both elective and urgent slots, and those with low priority are scheduled only in elective slots available to the consulting surgeon.
- In wait list booking, elective cases with any priority may be scheduled in any urgent slots available to the consulting surgeon, so long as there are no inpatients waiting in hospital.
- Emergency and urgent inpatients are placed on a current operating room schedule immediately. They are scheduled in urgent slots, if such are available; otherwise, previously scheduled operations may be cancelled to accommodate these cases.
- Inpatients whose need for surgery is less urgent are placed on the current schedule if there are available urgent slots; otherwise, they are scheduled in urgent slots available the next week.
- When scheduled operations are cancelled, patients with high or medium priority for elective surgery become inpatients, and those with low priority join the promise-to-readmit queue.
- The surgeons' service and vacation schedules are planned according to an 18-week cycle; the booking horizon is 36 weeks.
- Clinical decision-making that determines the progress of patients needing elective surgery from consultation priority groups to surgical priority groups was governed by binomial (branching) probabilities, as was the progress of patients needing urgent surgery from expedited consultation to surgery (as either inpatients or outpatients).

Table A1 shows the values of the model parameters that were used in all simulation runs, including the number of priority groups, arrival rates, branching probabilities and capacities. Complete model documentation, including the Statecharts specifications, is available from the authors.

TABLE A1. Simulation parameters

Parameter	Values
Priority groups	
Outpatient consultation	high, low
Operation	high, medium, low
Referral rate (patients per week)	
High priority for consultation	0.5
Low priority for consultation	6.5

TABLE A1. Continued

Inpatients	5.8
Emergency	0.5
Probabilities of progression	
Elective patients	
High consultation priority to high surgical priority	1
Low consultation priority to medium surgical priority	0.76
Low consultation priority to low surgical priority	0.24
Inpatients	
Inpatient assessment	0.5
Discharge and outpatient assessment	0.5
Capacity	
Number of surgeons	3
Weekly number of outpatient consultations	16 (8 on Monday, 8 on Tuesday)
Weekly number of elective slots	7
Weekly number of urgent slots	8