Deploying a Usability Laboratory to Assess Health Information Technology

Features

Human Factors Engineering
- Design and Implementation of a Hospital-Based Usability Laboratory: Insights from a Department of Veterans Affairs Laboratory for Health Information Technology

Operations Management
- Operations Research Methods Improve Chemotherapy Patient Appointment Scheduling

Teamwork and Communication
- Simulator-Based Crew Resource Management Training for Interhospital Transfer of Critically Ill Patients by a Mobile ICU

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- Counting Matters: Lessons from the Root Cause Analysis of a Retained Surgical Item

“Because many patient safety risks occur infrequently in the context of care, they may be difficult to observe during daily clinical practice. As much as possible, safety risks related to health information technology usability should be identified preemptively.”

—Design and Implementation of a Hospital-Based Usability Laboratory (p. 532)
Chemotherapy, the administration of pharmaceutical agents, usually by intravenous (IV) infusion, is a critical part of cancer treatment. Treatment protocols vary greatly in frequency (daily to monthly), duration (0.5 to 7 hours), number of treatments (one to indefinite), appointment date flexibility (none to +/- 2 days) and side effects; a sample protocol is shown in Table 1 (page 542). Protocols must be rigidly followed to achieve optimal clinical outcomes.

Scheduling chemotherapy appointments is complex and directly affects patient experience and operational performance. A large number of daily appointments with specific indications have to be arranged while accounting for patient time preferences; laboratory, radiology, and oncology appointments; and pharmacy capacity; as well as balancing nursing workload, conforming to nursing-shift schedules, and avoiding overtime. Potential consequences of inefficient processes include late patient notification lead times; considerable clerical rework; inefficient and unbalanced nursing and pharmacy resource utilization and workloads; heightened stress for patients and staff; and, possibly, negative health outcomes.

Cancer and chemotherapy are physically and emotionally challenging for patients and their families. In 2009, at the British Columbia Cancer Agency (BCCA) in Vancouver, Canada, uncertainty about appointment times was problematic—adding unnecessary anxiety for already stressed patients and their families in the process—because of the following:

- Patients frequently needed to coordinate transportation with family members, friends, or ride services, which often necessitated advance notice.
- Some patients needed sufficient notice to take pretreatment drugs.
- For patients living in more distant locations, uncertainty complicated travel plans and imposed additional financial burdens.

Confronted with increased patient volumes, new chemotherapy protocols, and budget restraints, chemotherapy appointment

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**Article-at-a-Glance**

**Background:** Clinical complexity, scheduling restrictions, and outdated manual booking processes resulted in frequent clerical rework, long waitlists for treatment, and late appointment notification for patients at a chemotherapy clinic in a large cancer center in British Columbia, Canada. A 17-month study was conducted to address booking, scheduling and workload issues and to develop, implement, and evaluate solutions.

**Methods:** A review of scheduling practices included process observation and mapping, analysis of historical appointment data, creation of a new performance metric (final appointment notification lead time), and a baseline patient satisfaction survey. Process improvement involved discrete event simulation to evaluate alternative booking practice scenarios, development of an optimization-based scheduling tool to improve scheduling efficiency, and change management for implementation of process changes. Results were evaluated through analysis of appointment data, a follow-up patient survey, and staff surveys.

**Results:** Process review revealed a two-stage scheduling process. Long waitlists and late notification resulted from an inflexible first-stage process. The second-stage process was time consuming and tedious. After a revised, more flexible first-stage process and an automated second-stage process were implemented, the median percentage of appointments exceeding the final appointment notification lead time target of one week was reduced by 57% and median waitlist size decreased by 83%. Patient surveys confirmed increased satisfaction while staff feedback reported reduced stress levels.

**Conclusion:** Significant operational improvements can be achieved through process redesign combined with operations research methods.
scheduling at the BCCA had exhausted the capabilities of the manual paper-based system introduced in the 1990s. The outdated booking process for chemotherapy appointments resulted in a significant waitlist for appointments and a large number of appointments being postponed and rescheduled. The manual scheduling process was time consuming, inflexible, and required considerable managerial and staff input, resulting in unbalanced workloads and inefficient resource utilization. Moreover, patients frequently did not receive final appointment notification until the day before their appointments. Because this process primarily resulted in clerical complexity, and no metrics were in place to assess notification time delays or appointment-time changes, senior management and clinicians were not widely aware of these limitations.

Limited literature on similar problems exists. Chemotherapy treatment planning has been studied extensively in terms of determining the optimal schedule of appointments from a clinical perspective.\(^1,2\) We incorporated this research in the design of the treatment protocols, which, in our case, affects the number and frequency of appointments and allowable tolerance but does not address operational issues. Quality and process improvement initiatives undertaken to increase throughput and utilization in chemotherapy clinics have been reported. For example, Gruber et al. reported that modifying patient flow and scheduling practices increased patient volumes—but also patient wait times and nursing staff overtime.\(^3\) Other studies have addressed scheduling complexity through the implementation of a “two-day” model, in which the patient receives chemotherapy on the day following his or her appointment with the physician.\(^4,5\) By separating the appointments, the two-day model reduces delays or cancellations that affect the chemotherapy clinic, although at the expense of patients having to visit the cancer center twice as often. The BCCA uses this approach.

An alternative approach has been to improve the chemotherapy pharmacy-dispensing process to reduce wait times, as shown in two studies that looked at pharmacy operations, particularly regarding the chemotherapy clinic.\(^6,7\) One study proposed a two-stage “rolling horizon” model to sequentially solve the booking and scheduling problems.\(^8\) In this innovative approach, traditional scheduling templates/rules are replaced by use of a decision-support tool to resolve the exact problem at hand. Unfortunately, this approach has not been implemented. Overall, reported initiatives recognize success to different extents and are mostly limited to specific parts of the overall chemotherapy delivery process. To the best of our knowledge, no previous study has simultaneously addressed booking, scheduling, and workload distribution issues and reported on the implementation of solutions.

**Methods**

**SETTING**

The BCCA, where this study was carried out, provides a provincewide, population-based cancer control program for the approximately 4.5 million residents of British Columbia and the Yukon, Canada. The Vancouver Centre (VC) is the largest of the six BCCA regional cancer centers. The Ambulatory Care Chemotherapy Unit (ACCU) at the VC delivers more than 15,000 appointments to more than 2,000 different patients each year and was the focus of this study.

**A THREE-PHASE STUDY**

The study, which was conducted between April 2009 and November 2010, had three distinct phases: (1) process review and assessment, (2) process improvement, and (3) project evaluation. Each phase addressed different objectives and used specific methods, as summarized in Table 2 (page 543).

**Phase 1. Process Review and Assessment (2 months).** In April 2009 a team consisting of oncologists and pharmacy and clinic staff...
managers, together with operations resources professionals, was established to undertake the study. The team reviewed chemotherapy scheduling operations at the VC through direct observation and interviews with staff (booking clerks, nurses, pharmacists, and managers), and developed process maps showing the key steps, relationships, and inputs in the booking process. Extensive data analysis was performed to objectively measure scheduling performance. Data records for a total of 19,300 appointments delivered between January 2, 2008, and May 1, 2009, were extracted from the appointment module in the Cancer Agency Information System (CAIS), which records all patient appointment booking information, including cancellations and changes, in the cancer center. Analysis of this data involved (1) summarizing daily appointment volumes by counts, nursing time requirements, and treatment protocol; (2) quantifying waitlist size at several points of time prior to the final appointment notification; (3) estimating resource utilization; and (4) summarizing the time between the first appointment entry and its intended date and the number of changes to the appointment time. Data analyses were performed with the NCSS Statis-
The Joint Commission Journal on Quality and Patient Safety

tical Software Package (NCSS; Kaysville, Utah).

To assess current patient experience, the team designed and administered a patient satisfaction survey, with 11 questions related to the appointment-booking process. The sample size was set at 340 to ensure sufficient power to detect meaningful changes after implementation (80% power to be able to detect a 10% difference in the proportion of patients with appointment notification lead time of three days or more at the .05 significance level). A test questionnaire was piloted for two days before finalization. The final questionnaire was appended to patient charts; the patient’s nurse handed the survey to the patient for completion. Surveys were administered until meeting the predefined quota. Formal statistical analysis of patient questionnaires used chi-square and Fisher's exact test for one-way analyses, and logistic regression to assess impact of qualitative factors on odds ratios.

**Phase 2. Process Improvement (13 months).** During Phase 2, the project team continued with weekly meetings to discuss the results of the Phase 1 analysis and brainstorm potential changes to the process that could lead to improved scheduling practices. A review of the literature focused on appointment scheduling in health care enabled the team to identify different scheduling models for different types of patients and clinics and to then evaluate their applicability to chemotherapy operations. To complement this information, the clinic manager consulted colleagues in other chemotherapy infusion clinics to inquire about their scheduling practices. In addition, the team conducted a Web search to investigate existing scheduling software and their features and capabilities.

**Discrete Event Simulation.** In June 2009 the team began developing a discrete event simulation of the scheduling process to explore the impact of potential system changes before implementation. A discrete event simulation, a form of computer-based modeling that is used to represent and modify variable complex systems, enables extensive “what if?” analysis and is an operations research (OR) technique commonly used in health care. The simulation was used to evaluate the potential impact of alternative scheduling practices on patients, the ACCU, and the pharmacy. The model entities were the appointment requests. All 19,300 historical appointments previously extracted and analyzed were now used as input to the simulation model to be booked for treatment under existing and modified practices. This allowed us to test different scheduling rules under realistic demand conditions for a period consisting of more than 350 treatment days. The following performance metrics were recorded and summarized for each replication: appointment notification lead time, waitlist size, ACCU utilization, and difference between requested and actual appointment date (where tolerance in treatment date was allowed). Because over-constrained capacity and inflexibility were major issues, the evaluated scenarios employed different capacity reservation rules and use of flexibility in treatment date. Specifically, simulation was used to investigate the following issues: (1) how much capacity to reserve for each appointment type; (2) how to best use the flexibility in appointment dates; (3) how far in advance to confirm final appointments; and (4) at what level to cap the waitlist. Each of these issues required specific numerical values or comparison of a range of options, so a simulation was required to determine the best combination of these factors.

**Mathematical Programming Model.** Because the redesigned appointment booking process significantly increased the complexity of scheduling operations, we developed a mathematical programming model and user-friendly interface to support the assignment of patients to nurses and time slots. Integer programming, also referred to as combinatorial optimization, is an OR technique that efficiently finds the best way of scheduling or allocating resources out of a very large number of possible alternative combinations. It has been widely used in health care and across a range of other industries, including the airline industry and manufacturing. Using mathematical programming involves two steps: (1) formulating the model and (2) obtaining solutions. In a model such as the one developed herein, values for a collection of decision variables, which can equal either 0 or 1, are selected by the optimization procedure to minimize an objective function subject to a series of constraints. The model structure is determined by the decision variables, the objective function form, and the constraints that represent the specifics of the problem at hand. We implemented the scheduling model by using a commercial optimization modeling language and commercial software designed to solve large, difficult problems quickly and with minimal user intervention. Model details are described in the Results section.

**Simulation Versus Optimization.** At this point, it is worth emphasizing the difference between simulation and optimization. The simulation model was used to measure the impact of any system change, including both process redesign and parameter variation. In this study, the focus was on macro-level changes, primarily concerning the allocation of tasks between the two phases of the scheduling process—booking and scheduling—and fine-tuning the booking phase. Scenarios were evaluated on the basis of patient notification lead time. The process redesign identified an opportunity to develop an optimization model to improve the second phase of scheduling. This optimization model allows some fine-tuning, such as varying shift start times,
Sidebar 1. Description of the Underlying Integer Programming Model Used to Schedule Appointments in the Second Stage of the Scheduling Process

**Decision Variables.** Binary variables were used to represent whether (1) or not (0) the “optimal schedule” assigns a patient to a specific start time in a particular nursing shift.

**Constraints.** Constraints in the formulation were of two types—hard constraints that must be satisfied and soft constraints that had some flexibility. The hard constraints were as follows:
- Each patient must be scheduled.
- Each nurse can deliver care to at most one patient at a time, and oversee treatment for up to four patients simultaneously.
- Mandatory appointment time constraints must be accommodated (e.g., start treatment after appointment with oncologist is completed; book sufficient time to complete infusion).

Soft constraints were as follows:
- The number of pharmacy preparations in any time slot should not exceed a prespecified value determined by available pharmacy resources.
- Appointments must conform to patient time preferences.
- Each nurse administers treatment to the same number of patients.
- The distribution of patients (both in number and complexity) throughout the day is balanced for each nurse.
- Clinical trial patients are assigned to a specialized nurse.

**Objective Function.** The objective function is that of a multi-objective integer program. Deviations in the soft constraints are weighted according to an importance factor and aggregated into a single objective to be minimized. Weights reflected the relative importance of the soft constraints while accounting for differences in units of measurement. Prior to their finalization, the weights were varied, and resulting schedules were shared with the chemotherapy unit manager until she felt the schedules were suitable. The model output included a report summarizing deviations from targets. After considerable preprocessing and elimination of redundancies, a typical instance of the integer program consisted of 12,500 variables and 1,900 constraints. Solution times varied between 20 and 120 seconds, depending on the volume of patients, available capacity, and individual appointment restrictions. Computation was terminated when the solution was within 20 units of the optimum (equivalent to a 1%–2% optimality gap) or after 300 seconds. Because the objective of this model was to automatically produce good schedules, finding the optimal schedule for each scenario was not required.

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Table 3. List of Metrics in the Evaluation Framework*

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<tr>
<th>Stakeholder</th>
<th>Quantitative</th>
<th>Qualitative</th>
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<tr>
<td>Patient</td>
<td>Appointment notification lead time</td>
<td>Satisfaction</td>
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<td></td>
<td>Waitlist size</td>
<td>Notification lead time for appointment date and time</td>
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<td></td>
<td>Days to first appointment</td>
<td>Appointment changes</td>
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<td>New process experience</td>
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<tr>
<td>Staff</td>
<td>Nursing workload</td>
<td>Satisfaction</td>
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<td></td>
<td>Pharmacy workload</td>
<td>Nursing workload</td>
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<tr>
<td>Organization</td>
<td>ACCU utilization</td>
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<td>Capacity availability</td>
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* ACCU, Ambulatory Care Chemotherapy Unit.

nursing break times, and the number of nursing shifts, but its primary focus is as an operational tool that produces daily appointment schedules. The quality of a solution to the integer programming was determined by its objective function value, which is described in Sidebar 1 (above).

**Implementation.** Implementation required careful planning, change management, and software development. Process changes and review of protocol guidelines were led by the clinic manager and oncologist in the project team. Information system modifications and staff training on both the new scheduling practices and the use of the new scheduling tool were performed by the OR analysts. New practices were communicated to patients and staff in the rest of the organization. The scheduling tool development involved designing and coding a user interface and report modules, creating a database, and extensive data processing. The tool was designed and implemented by the OR team and in-house programmers as a Web-based application and integrated with the optimization model and the CAIS. After the new scheduling system went live in June 2010, an OR analyst worked closely with the schedulers to address any problems in a timely fashion and refine the optimization model as needed. Ongoing monitoring and support has continued since.

**Phase 3. Project Evaluation (2 months).** The third and final project phase, evaluation, required additional data analysis and feedback from both patients and staff. A comprehensive evaluation framework was developed to measure project impact. Table 3 (above) lists the metrics that were used to investigate the impact of changes on patients, staff, and the organization. Quantitative measures (Table 3) refer to counts and time lapses that can be calculated objectively from appointment data, such as waitlist size or time between an appointment’s entry into the system and the appointment date. Two comparable periods, each comprising 85 appointment dates, were defined. The preimplementation period consisted of 4,901 appointment records between June 29, 2009, and October 23, 2009, and the postimplementation, 4,704 records between June 28, 2009, and October 22, 2010.

Qualitative measures (Table 3) refer to more subjective aspects and were derived from patient and staff satisfaction surveys and complemented with interviews of nurses, pharmacists, and the
Results

The results are provided by study phase. Phase 1 results were a detailed description of current scheduling operations and identification of process challenges. Phase 2 results consisted of a redesigned scheduling process and its implementation, including a new scheduling tool based on an optimization model. Phase 3 results constituted the formal postimplementation evaluation.

**PHASE 1. THE CURRENT SCHEDULING PROCESS AND IDENTIFICATION OF PROCESS CHALLENGES**

**Current Scheduling Process.** Three chemotherapy appointment types were distinguished: “new patient” (NP) appointments, “ongoing patient” (OP) appointments, and “clinical trial” (CT) appointments, accounting for 10%, 81%, and 9%, respectively, of the total appointment volume in 2010 at the VC. NPs provide the only external demand source. After a patient starts treatment and becomes an OP, his or her schedule (day, not specific time) is mostly determined by his or her treatment protocol. This distinction is important for two reasons: (1) nursing workload is considerably higher for NP appointments because the treating nurse must educate the patient about side effects and symptom management, as well as spend more one-on-one time with the patient; (2) congestion affects new patients the most; because there are a large number of inflexible OP and CT appointments, it may be difficult to find space for NP appointments. CT appointments (both NP and OP) are for patients following special regimens involving investigational drugs or protocols. As illustration, Table 1 provides the details of a sample breast cancer chemotherapy protocol. It shows that the treatment consists of eight appointment cycles, 14 (+/-1) days apart with resource requirements and delivery methods varying by cycle. Additional information includes clinical considerations such as pretreatment medications, dosage, and management of symptoms and side effects.

The process review indicated that a complex and inflexible system was in place to manage the complexity in scheduling a wide range of treatment types, resource requirements, and capacity constraints. Appointments were classified into “slot types” for treatment on the basis of appointment type (NP, OP, or CT) and nursing time requirement. For example, in Table 1 the designation CH90 refers to an OP appointment requiring 90 minutes of nursing time. Additional restrictions, such as “before 12:30,” accounted for treatment duration (chair time) by constraining the appointment start time. Treatment schedules, which varied by day of week to account for oncologist schedules, had a pre-assigned mix of slots types that together equaled the capacity of the clinic (number of patients and nurses). For example, one treatment day may have 20% of the slots labeled as CH90 for NP, 40% as CH60-OP, 10% as CH30-OP, and the rest for clinical trial patients labeled as CTCH of various types. Furthermore, each of the slots in these daily lists was preassigned to a nursing line and start time. In other words, the entire daily schedule was prespecified (Appendix 1, available in online article).

The process review revealed a two-stage appointment booking process represented by the process map in Figure 1 (page 547). In the booking stage, clerks in the ambulatory care unit (clinic) sought an available slot in the schedule, as described above, for the requested date. In the scheduling stage, clerks and the manager of the chemotherapy unit finalized the detailed treatment schedule, assigning specific patients to nurses.

The Booking Stage. In the first stage, for each chemotherapy treatment request, the clerk reviewed the appointment protocol (such as in Table 1) to determine the slot type needed and then searched through the CAIS for a suitable available slot (accounting for date and time restrictions). In the event that no slot was available in the initial stage, the patient was waitlisted for the requested date. At the time of this review, schedulers in this stage did not take into account appointment flexibility when seeking an appointment time and date. A CT nurse booked CT appointments separately in reserved slots in the schedule.

The Scheduling Stage. In the second stage, the chemotherapy manager and schedulers developed the final nursing schedule a few days before the actual appointment date. Each day, they would review and finalize the schedule for a date two to three days into the future. In this stage, all waitlisted patients had to be dealt with in one of three possible ways: (1) schedule for treatment the same day for which they are waitlisted; (2) schedule for treatment another day within the allowed tolerance; or (3) waitlist for another day within the tolerance. Unused CT slots were released at this point for non-CT patients. (The available data did not permit us to accurately determine the percentages of patients for each category). To accommodate as many patients as possible in the final schedule, the scheduling clerks,
together with the clinic manager, rearranged appointments using patients’ appointment-date flexibility, cancellations, released CT slots, and their in-depth knowledge of the needs of specific patients. If necessary, non-waitlisted patients who were booked in regular slots were postponed to allow more urgent patients to receive treatment. When necessary and possible within budget and staffing constraints, additional capacity was added to allow more patients to receive treatment on particular days. The schedulers and the clinic manager used a paper-based scheduling form and made all changes manually using their best judgment. This complex rescheduling process was repeated on a daily basis to finalize each treatment schedule.

Scheduling Challenges. The team concluded that this system had become incapable of effectively managing (1) 60 daily appointments; (2) 200 different drugs or drug combinations, each requiring differing amounts of nurse, chair, and pharmacy time; (3) schedules of more than eight nursing shifts, together using up to 33 chemotherapy chairs; (4) last minute-cancellations and urgent new appointments; and (5) patient time preferences or requirements. Overall, this process was stressful and tedious for clerical staff and managers. Further, schedules were unable to balance nursing workload and case complexity or level pharmacy demand throughout the day. This last issue was particularly relevant because chemotherapy drugs were costly and not mixed until the patient arrived to avoid wastage. On top of this complexity, future appointment demand was projected to increase.

Analysis of Historical Appointment Records. Analysis of historical appointment records revealed that more than 40% of chemotherapy patients at the VC received final appointment notification less than one week in advance of treatment; 6% had one day’s notice. Waitlists one week before the appointment date varied between 10 and 52 (median, 24) (Figure 2, page 548). These are large and variable numbers for a waitlist, considering that daily appointments throughout ranged between 57 and 62 patients.

Patient Satisfaction Surveys. A total of 362 patient satisfaction surveys were collected in a four-week period—two months before implementation of process changes. The baseline survey showed that patient satisfaction was directly related to appointment notification lead times; 27 (59%) of the 46 patients who were notified two or fewer days before their appointment were satisfied with the booking process, compared with the 233 (97%) of the 239 patients who received more than two days’ notice ($p < .0001$).

Issues Identified in the Process Review. The process review identified the following issues: (1) over-constrained capacity, (2) inefficient use of treatment-date flexibility, (3) uncontrolled waitlist, (4) untimely scheduling, and (5) unbalanced workload and complexity.

1. Over-constrained capacity. The use of 28 different slot types to address across protocol nursing time requirement differences (30–120 minutes), restricted start times, and other appointment specifics created frequent capacity conflicts,
ultimately resulting in a large number of waitlisted patients, even if there was available capacity, albeit for different slot type. With each treatment day having prespecified quantities of each slot type, these generic schedules were too inflexible to meet changing demand patterns.

2. Inefficient use of treatment-date flexibility. Figure 3 (above) shows that the vast majority of protocols were flexible with respect to appointment date, with more than 82% having a tolerance of at least plus-one day or minus-one day. Unfortunately, this tolerance was not accounted for in the first-stage scheduling decision so that appointments were waitlisted even when there was available capacity within the tolerance limit. As noted above, this tolerance was used at the second stage to create the final schedules. Prebooked appointments were often postponed to accommodate higher-priority patients, resulting in late appointment notification for both patients being rescheduled.

3. Uncontrolled waitlist. There was no limit on the waitlist size (Figure 2). Consequently, the second-stage schedulers faced significant challenges when they had to create a schedule for 30 or more waitlisted patients, more than 50 patients prebooked in regular slots, and a 65-patient treatment capacity limited by the number of nurses and infusion chairs, and pharmacy.

4. Untimely scheduling. The final scheduling stage took place between two and three days in advance of the treatment date, resulting in late appointment notification for patients whose appointments were waitlisted, rescheduled or postponed. This timing, although purposely chosen to be aligned with the time that unused CT slots were released and to account for late cancellations, had significant impact on patients.

5. Unbalanced workload and complexity. The second-stage manual scheduling process was not able to account for all of the nursing and pharmacy workload and complexity considerations.

**PHASE 2. SCHEDULING PROCESS REDESIGN, SCHEDULING TOOL, AND THE OPTIMIZATION MODEL**

*Scheduling Process Redesign.* The simulation model tested several factors in isolation and combination with others to identify their impact on the booking process. Different capacity configurations were analyzed, but we found that even with increased capacity, there were too many slot-type conflicts that resulted in waitlisted patients. We then proceeded to test the elimination of slot types and use of tolerance. The most promising scenarios showed that waitlist size could be reduced from a median of 35 and interquartile range (IQR) 29–43 under simulation of current conditions to 8 (IQR: 2–13) if all but CT slot types were eliminated, and even to 6 (IQR: 3–9) if tolerance in appointment date was used at time of booking (first stage) in addition to the elimination of slot types. The promising results encouraged the team to redesign the process incorporating these
changes. This also motivated a more detailed study to explore alternative ways of using appointment tolerance.\textsuperscript{15}

**Recommended Features for a Redesigned Booking Process.** On the basis of our assessment of the process maps and the simulation results, we recommended a redesigned booking process that incorporated (1) removal of booking constraints, (2) review and earlier use of booking tolerance flexibility, (3) constrained use of waitlist, (4) second-stage booking one week in advance of appointment date, (5) redesigned second-stage scheduling, and (6) development of a scheduling tool to balance workload and patient preferences.

1. **Removal of Booking Constraints.** Capacity conflicts in the booking stage could be reduced by combining the slot types as much as possible. After discussion with the clinic manager, it was agreed that 8 of the current 28 slot types had to remain for operational reasons: 3 for new patients, 2 for clinical trials, and 3 for specific short protocols. This would cause clerks in the first stage to face far fewer restrictions when seeking an available slot, thus simplifying their booking task considerably. Furthermore, patients would receive a confirmed date at this stage but not a confirmed time. The appointment time would be set in the second stage, when all constraints factors could be taken into account.

2. **Review and Earlier Use of Booking Tolerance Flexibility.** The clinic manager, in collaboration with oncologists, reviewed protocols for appointment date flexibility. This flexibility would now be used in the initial booking stage. When faced with no available capacity for the requested date, clerks now would search for an available slot in dates within the allowed tolerance; a patient would be waitlisted only when it is impossible to find an available slot within the tolerance limit.

3. **Constrained Use of Waitlist.** On each treatment date, clerks in the first stage process could waitlist up to five patients; if additional patients required appointments on that date, clerks had to contact the chemotherapy clinic manager, who would then proactively determine the best course of action, such as requesting special indications from the oncologists, or authorize an exception to waitlist the patient beyond the preset limit. Constraining the waitlist streamlined the second stage by limiting the number of appointments that needed to be rescheduled in the second stage.

4. **Second-Stage Booking One Week in Advance of Appointment Date.** In line with findings of the data analysis (specifically, the fact that more than 95% of appointments were requested more than seven days in advance), the second-stage scheduling would now take place a week before the appointment date instead of two to three days. This would provide patients with adequate notification lead time to prepare for their appointment.

5. **Redesigned Second-Stage Scheduling.** With the elimination of most slot types and their association to a start time and treating nurse, second-stage schedulers would now be faced with a clean sheet for assigning patients to nurses and time slots. They would have to assign all 65 patients to 9 nurses with 36 different start times (15-minute slots during the 9 hours of clinic operations). Waitlisted patients, now in much reduced volume, would still be handled in this stage and either selected for treatment or postponed to future dates within their allowed tolerance.

6. **Development of a Scheduling Tool to Balance Workload and Patient Preferences.** The more flexible redesigned second-stage scheduling created an opportunity to balance nursing workload and case complexity, level pharmacy workload, and account for patient time preferences, at the same time as the assignment of start time and nurse. It was evident that achieving all this in the second stage would be difficult without the support of a mathematical optimization model. To this end, the team developed Chemo SmartBook, a computer-based scheduling tool (described in detail in the next section), which simultaneously determines appointment times, balances workload and complexity across and within nursing shifts, levels pharmacy workload throughout the day, and accommodates patient time requirements and preferences. The process map in Figure 1 provides a schematic representation of the original booking process and the implemented changes.

The new system went live in June 2010, 15 months after the study began. In the two weeks before the go-live date, the two systems were run in parallel to address potential problems in advance. After the go-live date, an OR analyst worked closely with the second-stage scheduling team to address any problems in a timely fashion and refine the model as needed. Ongoing monitoring and improvement has continued.

**Scheduling Tool.** The review of commercial scheduler systems revealed that they were primarily appointment booking systems with common calendar-type features such as restrictions in type and length of appointments and automated booking for all appointments in a cycle. None provided the sophistication and intelligence to optimize schedules with the features we needed. Consequently, the project team developed the Chemo SmartBook, which was linked to the BCCA appointment information system. It contains the modules described in Sidebar 2 (page 550), the schedule optimizer being its most novel feature and the most significant development of this study. (Note that Chemo SmartBook is not a commercial product and remains in the research domain at present.)

**The Optimization Model.** A description of the underlying in-
Both pharmacy and nursing workload also showed significant improvements. The excess in the number of starts of treatment and drug preparations over what pharmacy staff can deliver per 15-minute time interval decreased by 44% and 31%, respectively. Similarly, nursing workload showed improved balance across nurses. The excess in the number of patients per nurse over ideal practice (up to seven patients per nurse) decreased by 50%.

**Qualitative Metrics.** The qualitative components in the project evaluation consisted of feedback from patients, managers, nurses, and booking clerks. To complement the quantitative metrics calculated from appointment data and the baseline patient satisfaction survey, a patient survey after implementation \((N = 352)\) was conducted. The survey methods and results are described in detail elsewhere.\(^4\) Highlights include the following findings:

Preimplementation, patients were 1.7 times more likely to have a date change \((95\% \text{ confidence interval [CI]}, 1.0–2.9)\), 2.3 times more likely to get an appointment date with less than three days notice \((95\% \text{ CI}, 1.4–3.9)\), and 3.2 times more likely to get the appointment time with less than three days notice \((95\% \text{ CI}, 2.1–4.9)\) when compared with postimplementation. Note that these results are self-reported and are consistent with results based on a complete analysis of appointment data, as reported in Table 4, albeit on the basis of different data summaries.

The number of patients satisfied with notification lead times for appointment time increased from 87.7% to 93.6% \((p = .014)\). Although both satisfaction levels were high, given the volume of appointments and patients, the effect is still noteworthy. Consequently with the reduction in appointment date changes and the increase in notification time, satisfaction improved after implementation.

Interviews with the chemotherapy unit manager revealed that the new processes simplified clerical work and reduced staff frustration levels, allowed more time to respond to problems, provided accurate resource utilization estimates, and increased nursing time efficiency and flexibility. The pharmacy manager noted that the process and changes balanced work flow and reduced the chance of errors, led to improved pharmacist and technician schedules, promoted collaboration and provided opportunity for broad input, and exceeded expectations for improving pharmacy operations.

Scale-based questions administered to the chemotherapy, outpatient, and pharmacy managers noted high satisfaction with the support provided, communication, and project execution and satisfaction with training and in achieving project expectations. A Web-based survey administered to 18 of the 22 nursing staff generated results from the evaluation, demonstrates that the changes implemented to scheduling practices significantly improved the process across a range of metrics. The primary metric, notification lead time, improved drastically; the median percentage of patients with less than seven days’ advance notice decreased by 57%. Further, the median number of patients who were notified less than three days in advance decreased by half.

Table 4 shows that, postimplementation, the number of patients placed on the waitlist decreased by 83% from a daily median of 24 to 4. This was encouraging but not surprising because the process redesign constrained the waitlist size and removed many first-stage booking constraints. Implementation of the new process also positively affected the metric “days to first available appointment,” a measure of system congestion. It reduced the median value of this measure by 67% from nine working days to three working days. This meant that the system had more capacity to schedule new patients earlier if needed.

**Phase 3. Evaluation of Impact**

**Quantitative Metrics.** Table 4 \((page 551)\), which shows selected results from the evaluation, demonstrates that the changes implemented to scheduling practices significantly improved the process across a range of metrics. The primary metric, notification lead time, improved drastically; the median percentage of patients with less than seven days’ advance notice decreased by 57%. Further, the median number of patients who were notified less than three days in advance decreased by half.

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**Sidebar 2. Modules in Chemo SmartBook**

1. **Nursing Schedule Processor.** Enables the unit manager to adjust daily clinic capacity by changing shift start times and breaks and adding or removing nursing shifts.

2. **Patient Record Processor.** Provides the scheduler with all the patient information, including time preferences, other appointments, and protocol and resource requirements. Potential problems or inconsistencies are automatically checked and flagged by the system for user correction. Patient information is obtained directly from the patient information systems.

3. **Schedule Optimizer.** Optimally assigns patients to appointment times while simultaneously accounting for patient time preferences, balancing workload and complexity across nurses, and limiting the number of treatments that the pharmacy needs to prepare in any period of time. Underlying this module is the integer programming model (Sidebar 1, page 545). Appendix 2 (available in online article) shows the output of the schedule optimizer, with summaries of the number of appointments starting in each 15-minute time block (right of the schedule) and the workload for each nurse (bottom of the schedule).

4. **Schedule Modifier.** Enables the user to fine-tune the schedule to account for late appointment changes, addition of urgent appointments, cancellations, or other unanticipated factors. A drag-and-drop interface facilitates these changes. Metrics are recomputed as appointments are changed.

5. **Report Generator.** Provides printable versions of chemotherapy unit and pharmacy work schedules and selected managerial reports.
staff in the chemotherapy unit, representing an 82% response rate, also showed positive results. More than 60% of the nurse respondents noted that the new process distributed patients more consistently within their shifts, 83% regarded the new scheduling process as an improvement over the old one, and 72% felt the project positively affected patients.

A separate Web-based survey administered to 9 of the 30 clerical staff, representing a 30% response rate, also gave high marks to the redesigned process. Unfortunately, the response rate was low and limits validity of these findings. Given the anonymous nature of the survey, we are unable to determine if the results were representative. More than 80% of the 9 appointment booking clerks who responded preferred the new process, and more than 40% noted a reduction in stress levels and in the amount of time required to book a patient; none reported increases in these measures. Clerical staff in the chemotherapy unit noted that the new scheduling system was easier to use and more efficient than the old system.

Discussion
A project with a single focus, namely to improve notification lead time, can have broad and far-reaching consequences, which, in this case, included developing streamlined processes that can accommodate evolving treatment protocols and increased future patient volumes; reviewing flexibility in chemotherapy appointment date guidelines; balancing pharmacy workload throughout the day; balancing nursing workload and case complexity across nurses; and creating a flexible, scalable, and adaptive tool that has enabled BCCA to efficiently schedule patients in the face of increasing demands.

The redesign of the chemotherapy appointment process entailed two significant changes: The addition of flexibility to the booking process and the introduction of Chemo SmartBook. Each of these changes to the scheduling process affected stakeholders differently. The enhancements to the patient experience (reductions in appointment notification lead time, waitlist size, and days to first available appointment) can be primarily attributed to the booking process redesign, while the improvements to staff workload distribution (pharmacy and nursing workload) are predominantly the result of using Chemo SmartBook to schedule appointments, as discussed in more detail below. However, we believe that each of these changes cannot be implemented independently, given that they were designed to support and complement each other.

The Patient Perspective
The scheduling-system changes significantly improved the patient experience through earlier notification of appointments, a reduction in last-minute changes, and improved satisfaction. This is mostly attributable to the addition of flexibility, reflecting the fact that (1) fewer appointment-type constraints for each slot in the schedule resulted in lower chances of being (unnecessarily) waitlisted, which in turn leads to notification of appointment date at time of booking; and (2) use of tolerance in treatment date at the first stage of the booking process expands the range of slots to which an appointment can be booked, which also reduces the chances for waitlisting. Further, by carrying out second-stage scheduling one week before the ap-
appointment date, patients received their appointment time notifi-
cation well in advance of their appointments.

THE STAFF PERSPECTIVE

Results show an important improvement in workload for
clerks, nurses, and pharmacists. A significant reduction in cler-
ical workload was achieved through (1) shorter waitlists through-
out the booking process, reducing the need for last-minute
scheduling changes; (2) fewer restrictions and more available ca-
pacity, making it easier to find dates for patient appointments;
and (3) automation of the second-stage scheduling process, sim-
plifying the allocation of treatment time and assignment of nurses
for each appointment. The first two results are mostly attributa-
table to the added flexibility in the booking process, while the third
to development and implementation of Chemo SmartBook.

For nursing staff, the scheduling tool directly improved work-
ning conditions by creating schedules with a more balanced work-
load distribution in terms of both patient numbers and case com-
plexity. Moreover, workload within each nursing shift was better
distributed to avoid highly stressful periods that could lead
to staff burnout and potentially affect care delivery.

Similarly, pharmacy staff were significantly impacted by
Chemo SmartBook. Careful consideration of pharmacy capacity
at the time of creating the schedule led to fewer instances in
which the number of treatment preparations exceeded pharma-
cists' and technicians' preparation capacity. Reduced pressure
contributes to decreased delays in dispensing drugs to patients
and potentially fewer errors.

ORGANIZATION PERSPECTIVE

BCCA’s strategic mandate is to “Ensure the provision and de-
ployment of resources to achieve maximal organizational effec-
tiveness,” “Establish the knowledge generation and application
paradigm within the provincial cancer control platform,” and
“Develop the ‘knowledge transfer’ environments, forums, pro-
cess and supports for innovation and adoption of new knowl-
dge.” This project advanced these strategic directions by sup-
porting BCCA’s effort to improve organizational effectiveness,
ereeﬃciency, engage staff, and develop innovative tools to
gain new efﬁciency.

This appointment-scheduling project shows how using OR
methods can improve the delivery of health care services. For ex-
ample, we found discrete event simulation to be an effective tool
for evaluating several alternative booking practices before select-
ing one for implementation, and integer programming can be
used to address scheduling challenges brought about by a signif-
icantly redesigned scheduling process. These innovative ap-
proaches to problem solving are particularly timely in the face of
projected increased demands and costs for health services. BCCA
now recognizes the potential for using OR methods to reduce
workloads, meet performance targets, eliminate redundant tasks,
enhance patient satisfaction, encourage strategic thinking, and
promote a culture of continuous improvement throughout the or-
ganization.

As an additional beneﬁt, the evaluation identiﬁed increased
opportunity for managers to think strategically, rather than
focusing most of their time on day-to-day operations. Examples
include optimizing shift scheduling, using nursing and pharmacy
resources more effectively, developing patient complexity scales,
and identifying opportunities for further process improvement.

With a restructured process and an automated scheduling
tool, BCCA is now better positioned to face operational chal-
 lenges. In particular, the growing need for chemotherapy treat-
ment is demanding an expansion in treatment capacity at the
VC infusion clinic. With the scheduling tool in place, the tran-
sition to scheduling a larger number of patients each day has
been seamless from the booking perspective.

The successful implementation of the two-stage booking
process and Chemo SmartBook at a second BCCA regional
treatment center in May 2012 demonstrates that the approach
described herein can be applied elsewhere. Except for some
minor information technology access issues, implementation was
seamless and well received. Formal evaluation of its impact is
under way. The team is also exploring other opportunities for
implementing this approach. One challenge is that many centers
use a one-day model, in which the testing, oncologist visit, and
chemotherapy appointment all occur on the same day. Conse-
quently, it is diﬃcult to assign a specific chemotherapy appoint-
ment time in advance because of potential upstream delays. The
analytical approach adopted herein, which combines process
mapping, simulation, and optimization, can address these chal-
lenges. These methods require expertise not commonly available
in health care organizations—as provided, for example, by in-
dustrial engineers, process engineers, and business analytics con-
sultants. We believe that this expertise will become even more
relevant in the future as more sophisticated approaches are re-
duired to address increased complexity in care delivery while
achieving improved resource utilization.

Subsequent to initial implementation in June 2010, improve-
ments to the optimization model and user interface in Chemo
SmartBook are making it more ﬂexible, faster, more compre-
ensive, and better able to meet user needs. Linkages to e-mail pa-
tient-notification systems and automated calling and reminder
systems also are being investigated, and we are undertaking a
similar project for scheduling radiotherapy appointments. Preliminary basic research will inform this process.15

Conclusions
Combining process analysis with well-proven OR methods can improve cancer care delivery in particular, and, we suggest, health care delivery in general. Although the use of process analysis is widespread and is a cornerstone of any quality improvement study, many applications require the use of more sophisticated tools, such as those described in this article, to review existing processes and identify appropriate process improvements. Studies in which simulation is beneficial are characterized by processes with significant variability and complex interactions that produce outcomes that cannot be easily anticipated. Studies in which optimization is beneficial are characterized by a large number of possible choices that makes it almost impossible to compare all of them to choose the best configuration.

As we described at the outset of this article, before we undertook this study, final appointment notification lead time—an important, yet not widely used, patient-focused metric—was not tracked, and senior management was unaware that late appointment notification was an issue. The multidisciplinary team of oncologists, clinic managers, and OR analysts that carried out the study, who were based at the BCCA, became aware of the issue in the course of regular communications with staff and patients. From the perspective of senior management, the situation was not “intolerable” because it simply flew under the radar. When oncologists wrote their chemotherapy orders, they generally assumed that appointments would be delivered when requested, so that patient notification lead times were not an issue they even thought about. Addressing the issue has led to a wide range of improvements in the delivery of chemotherapy, enhanced experience for patients, and the more efficient use of nursing, pharmacy, and clerical resources.1

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References

Online-Only Content
See the online version of this article for
Appendix 1. Paper-Based Nursing Schedule
Appendix 2. Screenshots of Chemo SmartBook Scheduler Output Showing Available Nursing Time, Assigned Patients, and Pharmacy and Nursing Workloads
The paper-based nursing schedule contained a template with generic appointment types preassigned to specific times and nurses. The same set of appointments was available as a list in the information system for clerks to book appointments as needed.
The "schedule optimizer/editor" module shows the assignment of appointments under each nursing shift. Schedules created by the optimization model can be edited by the user. Output includes number of appointment starts each 15 minutes and nursing workload indicators.