Reducing non-operative time: methods and impact on operating room economics

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Abstract: Improving operating room throughput is a perennial objective, but only incremental gains have been reported in the past. Recently, however, in situations characterised by short operative times, several teams have reported substantial increases in throughput, by addressing non-operative time rather than just its component, turnover time. The methods employed fall into five categories. Reviewing published results, we deduce the potential impact of each category on the reduction of non-operative time. Next, we estimate the reduction in non-operative time that must be achieved reliably to add cases to a 'full' operating room schedule, given a variety of operative times. Finally, we calculate potential incremental margin contributions of several of the reviewed perioperative systems, when implemented in a typical US hospital. We conclude that the benefits of introducing the methods outweigh their costs, but caution that hospitals need to increase their caseload of short procedures to realise these benefits.

Keywords: cost savings; healthcare process effectiveness; healthcare process redesign; hospital revenue; non-operative time; operating room efficiency; operating room throughput; opportunity cost.

Reference to this paper should be made as follows: Krupka, D.C., Sathaye, S. and Sandberg, W.S. (0000) ' Reducing non-operative time: methods and impact on operating room economics', *Int. J. Healthcare Technology Management*, Vol. 00, Nos. 0/0, pp.000–000.

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1 Introduction

Since operating rooms (ORs) incur high costs and generate high revenues, hospitals pursue a variety of methods to maximise the operating margins generated by these units. For example, they seek ways to reduce the cost of their supplies and introduce software systems to capture data that will help them ensure full reimbursement (Spring et al., 2007). Until the last few years, however, little attention was paid, in the healthcare literature, to the possibility of improving contribution margin (payments received, less the variable costs of staff and supplies) of ORs by introducing operational improvements in the near-OR perioperative system. This changed between 2004 and 2006. Several groups in the USA and Europe reported successful pilot studies to increase the number of cases performed in the standard daily schedule by reducing the interval between surgical procedures, commonly called non-operative time.

Working to reduce non-operative time appears to be appropriate if the procedures being performed in the room are short: improving OR throughput (defined as cases performed per unit of time) can allow an additional case to be performed in regular working hours. This could improve a hospital's contribution margin by roughly $1500 to $1800 for a case that consumes one hour of OR time (Dexter et al., 2002; Macario et al., 2001; Wachtel et al., 2005). By adding one such case daily, a hospital's contribution margin would increase by over $350,000 per year if the hospital were able to attract the additional surgical load.[1]

This article is organised as follows. In the next section (Section 2), we formally define non-operative time and its components, and introduce the scope of the perioperative system that will be considered in this article. Section 3 summarises recently reported operational results for non-operative time and its components, and classifies the methods used to achieve the results into five convenient categories. In Section 4, using data from the articles and assuming that it is possible to transfer results from one hospital setting to another, we deduce targets for the components of non-operative time that may be attained by employing several combinations of methods. Next, we present a simulation model to estimate the impact of non-operative time on the number of cases that can be performed during normal hours, and illustrate the magnitude of the effect for short cases. In Section 5, employing generally available data on compensation for the clinical staff in the USA, we estimate the potential annual financial impact on a hospital of a subset of the initiatives reported in the articles. We close in Section 6 by drawing attention to the practical challenges of introducing operational improvements across an entire OR suite.

2 Definition of terms

Non-operative time is defined as the interval during a case not directly devoted to performing the operative procedure. It is the sum of anaesthesia-controlled time (ACT) [2] and turnover time (TOT). ACT itself is the sum of two intervals:

- the OR Anaesthesia Time, the interval from the patient's arrival in the OR to the point at which the patient is turned over to the surgeon
- the OR emergence time, the interval that begins when the surgical dressings are complete and ends when the patient leaves the OR, whether or not the patient is awake.

TOT is defined as the interval between the departure of one patient from the OR to the arrival of the next. For reference, Table 1 summarises milestones in the OR and the intervals defined by the milestones that will be referred to here.

Table 1 Summary of milestones and intervals referred to in this article

Milestone name	*Definition*
Patient in room	Patient crosses OR door threshold into OR
Ready for surgical prep	Patient is deemed ready for surgeon to begin positioning and skin prep (also called the anaesthesia finish time)
Surgery finish	Dressing applied or drapes off if no dressing
Patient out of room	Patient crosses OR door threshold out of OR
Interval name	*Definition*
Operative time	Ready for surgical prep to surgery finish
Non-operative time*	previous *patient out of room* to current *patient ready for surgical prep* PLUS *surgery finish* to *patient out of room*
Turnover time	previous *patient out of room* to current *patient in room*
OR anaesthesia time	*Patient in room* to *ready for surgical prep* (also called *anaesthesia finish*)
OR emergence time	*Surgery finish* to *patient out of room*
OR total process time	previous *patient out of room* to current *patient out of room*

Notes: Where standard terms are available in the American Association of Clinical Directors Procedural Times Glossary (http://aacdhq.org?Glossary.htm, accessed 12/25/04), they are used in this report.

* One could also define non-operative time as 'previous *patient surgery finish* to current *patient ready for surgical prep*'. This is correct if one takes a turnover-centric view, but it combines the non-operative intervals of two cases when defined this way. This is problematic if one considers the example of a very complex case following a simple one. By associating the non-operative time in question with the preceding case, then that case will get the complex (and hence time consuming) setup lumped into its statistics, or conversely, the complex case will have the previous simple wake-up and cleanup lumped into its statistics.

Assigning responsibility for performance in each of the intervals is not as straightforward as their names would suggest. For example, although the term 'anaesthesia-controlled time' suggests that the anaesthesia team controls the duration of the interval, such is not always the case. Consider what happens when the patient is brought to the OR, but the surgeon is not present. Sound practice dictates that the anaesthesia team will await the surgeon's arrival before proceeding with anaesthesia induction. Likewise, any elapsed time between the end of the anaesthesia team's induction activities and the beginning of prepping and draping, due to the surgeon's reviewing plans, imaging, etc., or extensive positioning efforts might all be counted in the ACT portion of the non-operative time. Similarly, OR emergence time and hence ACT, may be significantly extended if the recovery area is congested, and the patient cannot be moved from the OR. Thus, while a long ACT could result from difficulties or inefficiencies attributable to anaesthesia care, it may reflect a host of other problems, beyond the control of the anaesthesia team, and possibly beyond the control of anyone in the OR.

Similar considerations apply to reported values of TOT. In principle, TOT consists of two activities: room cleanup and instrument set up. However, a long average TOT cannot be ascribed simply to the slow pace of the staff responsible for the two activities. For example, if a patient is late, if instruments are missing, if patient documentation or preoperative evaluation is incomplete, or if a surgeon or anaesthesiologist is delayed elsewhere, the associated delay is reflected in an extended TOT.

The foregoing discussion leads to the conclusion that an effective programme to reduce non-operative time must take into account a very large number of factors spanning the near-OR perioperative system: improvements confined to the OR are unlikely to suffice. Thus, non-operative time is the most appropriate interval for consideration in process improvement efforts, because it reflects the global performance of the perioperative system. From this it follows that an effective process improvement programme requires the participation of staff from all parts of the system.

3 Methods for reducing non-operative time

In this section we begin by summarising recent reports of substantial reductions in non-operative time achieved by groups working in Finland, Germany and the USA. (Cendan and Good, 2006; Friedman et al., 2006, Hanss et al., 2005; Harders et al., 2006; Sandberg et al., 2005a; Torkki et al., 2005). We then introduce a classification of the methods in the studies. This will set the stage for Section 4, in which we generate hypotheses regarding attainable values for non-operative time.

Table 2 presents a summary of the recent studies. For each study, the table lists the modifications to the standard or control procedures, commonly used at the host institution, that were introduced to achieve the performance improvements. Reductions in turnover time; anaesthesia-controlled time, including its components when reported, and non-operative time, are used as measures of improved performance. Most of the studies also reported increased OR Throughput, expressed as additional cases per day. Further details on the studies are drawn together and cross referenced for the reader's convenience in Appendix A.

Table 2 begins with five studies that involved procedures using primarily General Anaesthesia (GA), and follows with two in which primarily Regional Anaesthesia (RA) was administered. Within each of the two groupings, the studies are listed roughly in the order of diminishing complexity of intervention. Thus, for studies that used primarily GA, Table 2 begins with the work of Hanss et al. (2005) who used both induction and emergence areas, and awakened the patient in the emergence area. It concludes with the Cendan study (Cendan and Good, 2006), which relied primarily on process modifications. In the RA category, the work of Smith et al. (Anonymous, 2006, Smith et al., 2005) is listed first because they used a special facility for opening instruments.

Table 2 Modifications to standard or control procedures and results achieved

Authors	*Modifications to standard or control procedure*	*Turnover Time (min)*	*Anaesthesia-controlled Time (min)*	*Non-Operative Time (min)*
Hanss et al. (2005)	Added an anaesthesiologist and a nurse in the induction area (also used in the control process) to administer anaesthesia to the next patient while the previous patient was still in the OR. Patient positioning took place in the induction area. Moved patient, while still under anaesthesia following surgery, to a pre-PACU emergence area	38 ± 24 → 25 ± 15 (mean ± SD)	Not reported	43 ± 23 → 28 ± 18
Sandberg et al. (2005a)	Added an induction area where anaesthesia was administered, upon signal that OR was almost ready for the next patient Introduced mobile OR table tops Added pre-PACU emergence area to monitor patient following emergence in the OR Introduced extensive parallel processing by: establishing a 1:1 staffing ratio for anaesthesiologists; adding a perioperative nurse to take responsibility for patient from OR to PACU; assigning one member of Housekeeping to the OR; and occasionally using extra nurse during turnover	36 (34–38) → 22 (21–23) (mean, 95% CI)	OR Anaesthesia Time: 13 (12–15) → 3 (2–3); OR Emergence Time: 13 (12–15) → 10 (9–11)	67 (64–70) → 38 (35–40)
Torkki et al. (2005)	Set up induction area where anaesthesia was administered, occasionally in parallel with emergence of the previous patient in the OR Added a team of two nurses and one anaesthesiologist to accomplish the above Employed OR mobile table tops Eliminated many delays between surgical preparation and surgery and between the departure of the patient from the OR to start of room clean up	Not reported	Not reported	Non-operative time (defined by the authors as 'the time starting when surgical closure was finished and ending by the incision of the next patient'): 73 ± 51 → 64 ± 43

Table 2 Modifications to standard or control procedures and results achieved (continued)

Authors	*Modifications to standard or control procedure*	*Turnover Time (min)*	*Anaesthesia-controlled Time (min)*	*Non-Operative Time (min)*
Harders et al. (2006)	Introduced extensive parallel processing by modifying responsibilities and processes of the following: circulating nurse, anaesthesiologist, nurse anaesthetist, housekeeping Introduced mobile OR table tops Initiated a programme to identify and reduce sources of delays	43 ± 22 → 26 ± 11 (mean ± SD)	OR Anaesthesia Time: 12 ± 6 → 9 ± 4 OR Emergence Time: 10 ± 7 → 8 ± 6	65 ± 22 → 42 ± 13
Cendan and Good (2006)	Introduced process modifications to achieve parallel processing: (a) charge nurse comes to the OR to cover for the circulating nurse, who goes out to check in the next patient in the pre-operative area and obtains medications for the next case. (b) Anaesthesia technician is assigned some of the turnover tasks previously performed by the anaesthesiologist Electronic signature and document transmission used to eliminate need for charge nurse to deliver printed documentation to PACU.	For 'large scale' study 44 ± 23 → 28 ± 15 (Mean ± SD)	Not reported	Not reported

Table 2 Modifications to standard or control procedures and results achieved (continued)

Authors	*Modifications to standard or control procedure*	*Turnover Time (min)*	*Anaesthesia-controlled Time (min)*	*Non-Operative Time (min)*
Smith et al. (Anonymous, 2006, Smith et al., 2005)	Introduced parallel processing by (a) administering spinal anaesthesia in an 'induction room environment' staffed by 2 circulating nurses who alternate patients; (b) having a specially designated PACU nurse come to the OR following surgery to transport patient to PACU Participating staff members communicated via walkie-talkies Experienced member of environmental services assigned to assist with room clean up Instruments opened in a sterile facility near the OR; covered; transported to OR; and uncovered following a special protocol	TOT: 30 → 12; patient time in room to incision: 52 → 32. For more than half of turnovers; patient out of OR to next incision: 35	Not reported	Not reported
Friedman et al. (2006)	Introduced process modification to achieve parallel processing as follows: During turnover, sedation and local block were administered in an induction area, set aside within the pre-op area instead of being administered in the OR, which had been the usual practice. Prepping was completed in the OR No incremental resources applied	TOT: 24 ± 0 (concurrent control) and 33 ± 30 (historical control) → 18 ± 11 (Mean ± SD)	Not reported	Not reported

The seven studies demonstrate the feasibility of substantially decreasing non-operative time, thereby increasing the potential Throughput of an OR suite. The results appear to stand in contrast to the work of Dexter et al. (1995) over ten years ago, who concluded that hospitals could not benefit from reducing non-operative time because they would not be able to reduce it enough to reliably schedule an additional case. The apparent discrepancy has its roots in the magnitudes of the operative times. For example, Dexter et al. (1995) reported a surgical time of 148 ± 39 minutes for a laparoscopic cholecystectomy, while Sandberg, et al., report an operative time of 97 minutes for *all* cases, (see Table 5 in Sandberg et al. (2005a) OR Total Process Time minus Non-Operative Time for all laparoscopic cases).[3] By contrast, non-operative time in traditional ORs has not declined. Dexter et al. (1995) reported a non-operative time of 65 minutes, consisting of ACT of 28 ± 13 minutes and TOT of 37 minutes, while in the Sandberg study, non-operative time for laparoscopic cases in the typical OR environment was 69 minutes (Sandberg et al., 2005a). Simply stated, when average operative times are approximately 90 minutes or less, the number of turnovers during a reasonable day's schedule becomes large enough to allow enough opportunities for non-operative time saving (i.e. turnovers) to sum up to at least one additional OR total process time (Sandberg et al., 2005a), into which an additional case can be routinely scheduled.

In the seven studies, the methods used to reduce non-operative time can be classified into five categories.

3.1 Process modifications

This method is based on restructuring the responsibilities and activities performed by members of the OR team so that their idle time during the non-operative interval is minimised. In practical terms, it means identifying how to keep personnel simultaneously occupied, a strategy referred to as parallel processing (Sandberg et al., 2005a). In the traditional approach, most tasks are started when the preceding tasks are complete. In other words, tasks are accomplished by serial processing. By contrast, a parallel processing environment depends on establishing a set of accurate and reliable synchronising signals so that parallel activities start in concert.

All of the studies involved process modifications, and all introduced parallelism in one form or another. In three instances (Hanss et al., 2005; Sandberg et al., 2005a; Torkki et al., 2005), the patient was anaesthetised while the OR was being prepared; Harders et al. (2006) initiated room clean-up while the patient was still present and split the roles played by the members of the anaesthesia team during turnover; and Cendan and Good (2006) brought the Charge Nurse to the OR to allow the Circulating Nurse to carry out some tasks that had traditionally been performed during the non-operative interval.

3.2 Addition to staff

An obvious strategy for reducing non-operative time is to add personnel who take responsibility for one or more of the tasks being performed in parallel. For example, a nurse may be temporarily injected into the turnover process to carry out some of the tasks normally assigned to another nurse (Cendan and Good, 2006; Sandberg et al., 2005a). Some situations dictate that additional personnel be assigned: it is not permissible to anaesthetise a patient in the induction area while another patient is in the last stages of a procedure in the OR without adding at least a medically supervised anaesthetist to the team.

3.3 Technology

For the five studies using primarily GA, mobile OR table tops were used in all but the Cendan study (see Sandberg et al. (2005a) and Stahl et al. (2006) for illustrations). When correctly employed, they are used to transport the patient to and from the OR, as well as during the procedure. Thus they eliminate patient transfers in the OR, offer the possibility of attaching patient monitors in the preoperative holding area, rather than in the OR, and contribute to the reduction in TOT by eliminating the need to clean and prepare the operating table in the OR at the conclusion of the procedure. Mobile OR table tops also save time by enabling cable management systems, as illustrated in Sandberg et al. (2005a).

Technological solutions could also take the form of software, although none of the seven studies comment on its use to achieve improved performance. However, systems exist to create one or more properly timed, synchronising alerts when prompted with a single manual entry.[4] Providing automated alerts and synchronising signals to notify OR team members that planned and unplanned events have occurred is an active area of current research (Moss and Xiao, 2004; Sandberg et al., 2005b; Xiao et al., 2005).

3.4 Facilities

All studies that included induction of anaesthesia outside the OR made use of special facilities. Induction rooms and 'early recovery' areas adjacent to the OR are examples of a special facility to support parallel processing. Induction rooms are common in parts of Europe (Bromhead and Jones, 2002) but rare in the USA. Smith et al. (Anonymous, 2006, Smith et al., 2005) used two facility modifications: they set up a special area within the preoperative holding area to administer RA, and they relied on a specially designated sterile setup area near the OR to lay out the instruments for the next case.

3.5 Delay elimination

Although application of the four methods described above reduces non-operative time, it is virtually certain that maximum Throughput cannot be achieved without the systematic elimination of delays that occur in the perioperative system near ORs. The delays arise from missing instruments, consent forms not signed, slow response from the laboratory running tests for a patient in the preoperative area, missing clinical staff members, etc. Two of the studies specifically mention such delays: Harders et al. (2006) report setting up a process to eliminate them, while Torkki et al. (2005) cite the impact of eliminating delays.

As shown in Table 3, all of the studies invoked at least two methods to reduce non-operative time; four studies applied at least four. This suggests that an institution, embarking on a programme to increase OR Throughput by reducing non-operative time, needs a process to select the methods to apply. In doing so, it will need to consider the potential impact of each method, the expense associated with the intervention, the likelihood that a given method will work in the local environment, and the difficulty of introducing the change. In the following section, we develop hypotheses regarding the potential reductions of non-operative time resulting from deploying subsets of the interventions. We also introduce an analytical model to estimate the impact of non-operative time on OR throughput, and illustrate its application in a few special cases.

Table 3 Summary of methods applied to reduce non-operative time in the work described in Table 2

Authors	*Methods applied to reduce non-operative time*				
	Process modifications	*Additions to staff*	*Technology*	*Facilities*	*Delay elimination*
Hanss et al. (2005)	Yes	Yes	Yes	Yes	Not mentioned
Sandberg et al. (2005a)	Yes	Yes	Yes	Yes	Not mentioned
Harders et al. (2006)	Yes		Yes		Yes
Torkki et al. (2005)	Yes	Yes	Yes	Yes	Yes
Cendan et al. (2006)	Yes	Yes			Not mentioned
Friedman et al. (2006)	Yes			Yes	Not mentioned
Smith et al. (2005)	Yes	Yes	Yes	Yes	Not mentioned

4 Impact of the methods on reducing non-operative time and increasing OR throughput

Examination of Table 2 reveals suggestive relationships among the times attained in the different studies. For example, the mean turnover times for four studies employing predominantly GA are very similar, ranging from 22 minutes (Sandberg et al., 2005a) to 28 minutes (Cendan and Good, 2006). The study that brought anaesthetised patients into the OR, and moved them to the early recovery area (Hanss et al., 2005) achieved an ACT of approximately three minutes (mean non-operative time of 28 minutes and a mean turnover time of 25 minutes), while the Sandberg study (Sandberg et al., 2005a) reports a mean OR anaesthesia time of three minutes. If the ACT of Hanss et al. (2005) were evenly apportioned between induction and emergence, then the two OR anaesthesia times would be very close. Finally, the rank order of non-operative times for Harders et al. (2006), Sandberg et al. (2005a) and Hanss et al. (2005) – all of whom employed mobile OR tables – is consistent with the expectation that applying additional interventions should result in progressively shorter values. The relationships described above suggest that the results achieved in different settings may be somewhat transferable. We, therefore, propose this as a hypothesis to be tested in future studies.

On the basis of this hypothesis (or, in other words, with an overt but untested assumption that the operational results are roughly transferable between institutions), we now proceed to estimate the impact of some of the interventions designed to improve throughput. We begin with the work of Hanss et al. (2005) because they applied the most complete set of interventions, including both induction and emergence areas, and achieved the shortest mean non-operative time, 28 minutes. For the sake of subsequent discussion and, as shall become evident without significant impact on our conclusions, we assume that the OR anaesthesia time and the OR emergence time achieved by Hanss, et al. (2005), were two minutes and one minute, respectively.[5] These values are shown in Table 4, which also includes values of other important intervals listed in Table 2.[6]

Table 4 Benchmark times for elements of non-operative time and the special facilities and equipment employed in achieving them

Interval	*Benchmark*	*Special facility*	*Special equipment*	*Reference(s)*
OR anaesthesia time	~ 2–3 min	Induction room	OR mobile table tops	Hanss et al. (2005), Sandberg et al. (2005a)
OR anaesthesia time	~ 8 min	None	OR mobile table tops	Harders et al. (2006)
Turnover time	~ 12 min	Instrument set up room		Smith et al. (2005)
OR emergence time	~ 1 min*	Emergence area	OR mobile table tops	Hanss et al. (2005)
OR emergence time	~ 8 min	None	OR mobile table tops	Harders et al. (2006)

Note: *Authors' estimate based on the time it might take to transfer the mobile table top to a transport shuttle and move the patient out of the OR.

Using the data of Table 4, and the assumption that the mean non-operative time of 28 minutes reported by Hanss et al. (2005) is the best that one can achieve, using all of the methods indicated, we proceed to estimate the non-operative times that can be achieved as, one by one, the following resources to reduce non-operative time are withdrawn: emergence area, induction area and mobile OR table tops.

According to Table 4, when mobile OR table tops are used, and when a patient has been anaesthetised outside the OR but awakened in the OR, an average of eight minutes can be expected to elapse, from the time that the dressings are applied, to the moment that the patient leaves the OR. Thus, one might expect that, under such circumstances, the mean non-operative time should increase to 35 minutes (28 minutes plus the difference in OR emergence times of seven minutes).[7] The result is consistent with the mean non-operative time of 38 minutes recorded by Sandberg et al. (2005a), who awakened their patients in the OR. If the patient were anaesthetised in the OR rather than in the induction area, the mean non-operative time would be expected to rise to about 40 minutes. This follows from the first two rows of Table 4, which suggest that, for a patient on a mobile table top, the mean OR anaesthesia time is about five minutes longer when the patient is anaesthetised in the OR. This difference is consistent with an estimate of the time required to move a patient from a gurney to the OR Table, and to attach leads. This estimate of a 40-minute non-operative time is consistent with the time of 42 minutes reported by Harders et al. (2006).

To compute the impact on non-operative time of eliminating the mobile OR table tops, i.e. reverting to methods typically employed in the USA., we require an estimate of their effect on

- both components of ACT
- TOT resulting from the elimination of cleaning and preparation of an OR table between procedures.

The results of Harders et al. (2006) suggest that the impact on ACT is approximately five minutes. If we hypothesise that an additional three minutes of TOT can be saved by eliminating the need to clean and prepare the OR table, the total impact (of removing the mobile OR tables) on non-operative time would be to add eight minutes. Thus, starting with the results of Hanss et al. (2005), and allowing the assumption that results are roughly transferable between institutions, our hypotheses suggest that a perioperative system, without induction or emergence areas, which does not use mobile OR table tops or extra staff, would have a non-operative time of 48 minutes (Harders et al., 2006; Sandberg et al., 2005a).

The above estimates are summarised in Table 5. Subject to the limitations of our assumptions, it may be interpreted as follows. By introducing parallel processing and other process improvements and by eliminating many sources of delays, a hospital may expect to achieve an average non-operative time of approximately 48 minutes for short, relatively simple cases. If it then introduced a system of mobile OR table tops but did not add staff, it could expect to reduce the average non-operative time to about 40 minutes. If it then created an area where patients, on mobile OR table tops, were anaesthetised before being transported to the OR, it could expect to further reduce non-operative time by five minutes, provided that it made appropriate additions to the perioperative staff. Finally, if it decided to awaken its patients in an emergence area, it could expect a mean non-operative time of about 28 minutes.

Table 5 Estimates of non-operative time based on starting with the results of Hanss et al. (2005)

Methods applied	*Non-operative time (min)*
Emergence area, induction area, OR mobile table tops, additional staff as required	28
Induction area only, OR mobile table tops, additional staff as required	35
No special facilities, OR mobile table tops, no additional staff	40
No special facilities, no additional staff	48

It is unlikely that a hospital would wish to or could apply all of the foregoing methods to reduce non-operative time. To select the most suitable ones, it would need to assess the financial consequences. Below, we describe the first of two steps to conduct this assessment: a method to estimate the impact of reducing non-operative time on the number of cases that can be performed within a hospital's standard, scheduled, OR hours.

How will the number of cases that a hospital can schedule into an OR during its standard working hours depend on non-operative time? The answer depends on the cases' operative times. The shorter the operative times and the longer the hospital's standard OR hours, the higher is the probability of fitting in one or more additional short cases during regular hours. If the probability of exceeding the allotted time is low, say 5%, one can conclude that the cases fit. If, on the other hand, the probability is moderately high, say 30%, then OR management must be prepared to exceed the allotted schedule and to pay for overtime on 30% of the days.

To calculate the number of cases that can be performed in a day, we require the probability distributions of the operative and non-operative times. If both were normally distributed, the calculation would be straightforward. However, operative times have been shown to have a lognormal distribution (Strum et al., 2000), and the distribution of non-operative time is likewise lognormal (Sandberg, 2005, unpublished results). Because of this mathematical complication, we have arrived at the answer by using a simulation model, executed with Microsoft Excel. Such simulation methods are commonly used to estimate the probability of completing a project within a target interval (Lu and Abourizk, 2000).

With the model, further described below, we estimated the probability of fitting a number of short, nominally identical, cases – with mean operative times ranging from 30 to 60 minutes – into the daily schedule, as we varied the non-operative time. (The situation we modelled is, admittedly, unusual; we selected it to simplify the exposition.) Specifically, we performed simulations to estimate the distribution of T, the total OR time for the day, expressed as

$$\begin{aligned} T &= n\,\text{lognormal(operative time)} + (n-1)\,\text{lognormal(non-operative time)} \\ &\quad + \text{lognormal(OR anaesthesia-controlled time)} \approx n\,\text{lognormal(operative time)} \\ &\quad + n\,\text{lognormal(non-operative time)} - \text{lognormal(turnover time)} \end{aligned}$$

where n is the number of cases to be performed in the OR within a given interval, e.g. eight hours. The first two terms in the equality represent the n operative intervals and the $n-1$ non-operative intervals between them, while the third term accounts for the OR anaesthesia time associated with the first case of the day and the OR emergence time of the last case. In the approximation, we used the fact that anaesthesia controlled time can be expressed as the difference between non-operative time and turnover time. In performing the simulation, we assumed that the turnover time (in the last term) has a lognormal distribution with a mean of 20 minutes and a standard deviation of 6.5 minutes.[8]

Rather than arbitrarily select the variance for each operative and non-operative time, we assumed values for the ratio of the variance to the square of the mean. This ratio, the squared coefficient of variation (SCV) (Hopp and Spearman, 1996), is a convenient measure of the relative variability of a random variable. If SCV = 0, variability vanishes, and one can simply add up the mean times to determine how many cases could fit into the day. If SCV = 0.2, the standard deviation is 45% of the mean.

The distribution of the total OR time, T, was estimated by running the simulation 1000 times from two up to nine cases per day, while varying the mean non-operative time from ten to 70 minutes. The probability of exceeding the day's scheduled duration – set to be either 480 or 540 minutes – was deduced from the resulting estimated distribution by using Excel's PERCENTRANK function.

Figures 1–4 show the probability of exceeding the daily schedule of either eight- or nine-hour days for cases with mean operative times of 60, 50, 40 and 30 minutes. The simulations assume an SCV of 0.3 and 0.2 for the operative and non-operative times, respectively, an assumption generally consistent with the data presented in the articles summarised here. (The kinks in the curves, such as seen on Figure 1, are an artefact arising from the finite number of simulations and from sampling the tail of the distribution). Results are presented for non-operative times up to 70 minutes because that is a reasonable upper bound for the short cases under consideration. A 50% probability of fitting the cases into the daily schedule, the upper limit for the results shown here, is roughly equivalent to adding up the means of the times in the equation that defines T. For example, Figure 1 indicates that five cases with 60-minute operative times and characterised by a 42-minute mean non-operative time will have a 50% probability of fitting into an eight-hour day. By simply using the means of the intervals and not considering variability, one would estimate that the non-operative time would have to be approximately 40 minutes to enable the five cases to fit into the eight-hour day.

Figure 1 Probability of exceeding the allotted daily schedule as a function of non-operative time for cases with mean operative time of 60 minutes. The calculations are based on the assumption that the squared coefficients of variation for the operative and non-operative time are 0.3 and 0.2 respectively

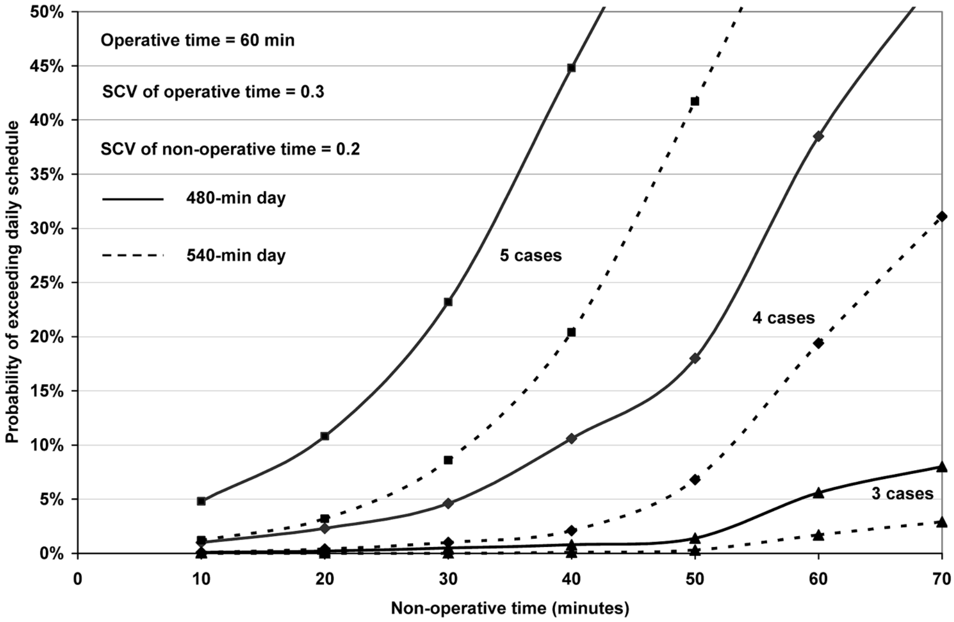

Figure 2 Probability of exceeding the allotted daily schedule as a function of non-operative time for cases with mean operative time of 50 minutes. The calculations are based on the assumption that the squared coefficients of variation for the operative and non-operative time are 0.3 and 0.2 respectively

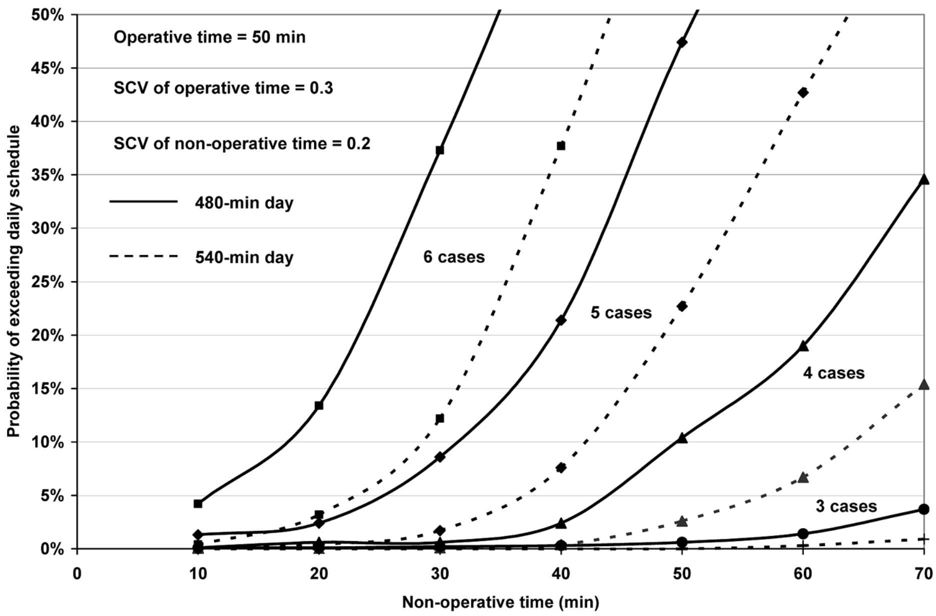

Figure 3 Probability of exceeding the allotted daily schedule as a function of non-operative time for cases with mean operative Time of 40 minutes. The calculations are based on the assumption that the squared coefficients of variation for the operative and non-operative time are 0.3 and 0.2 respectively

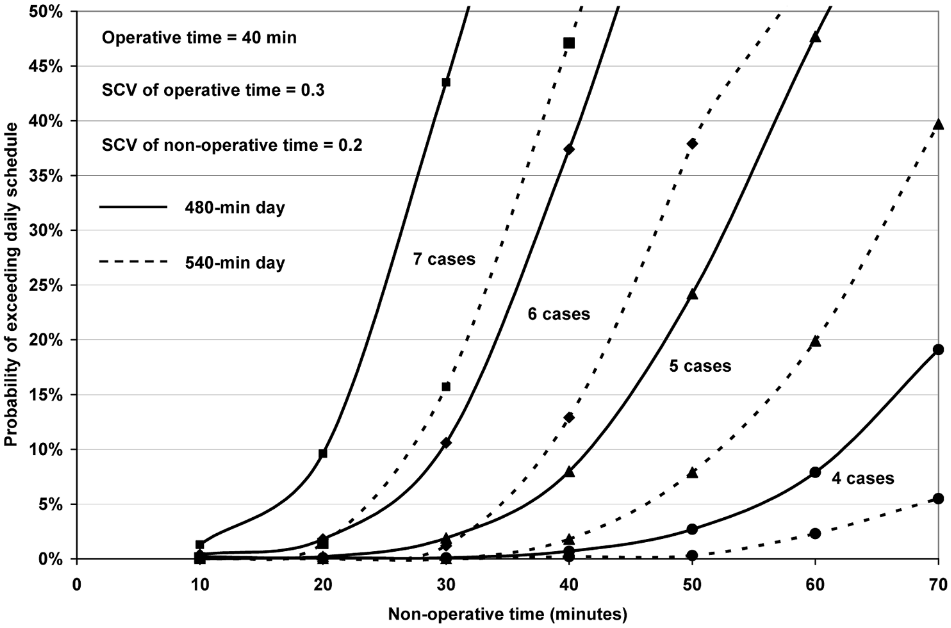

Figure 4 Probability of exceeding the allotted daily schedule as a function of non-operative time for cases with mean operative time of 30 minutes. The calculations are based on the assumption that the squared coefficients of variation for the operative and non-operative times are 0.3 and 0.2 respectively

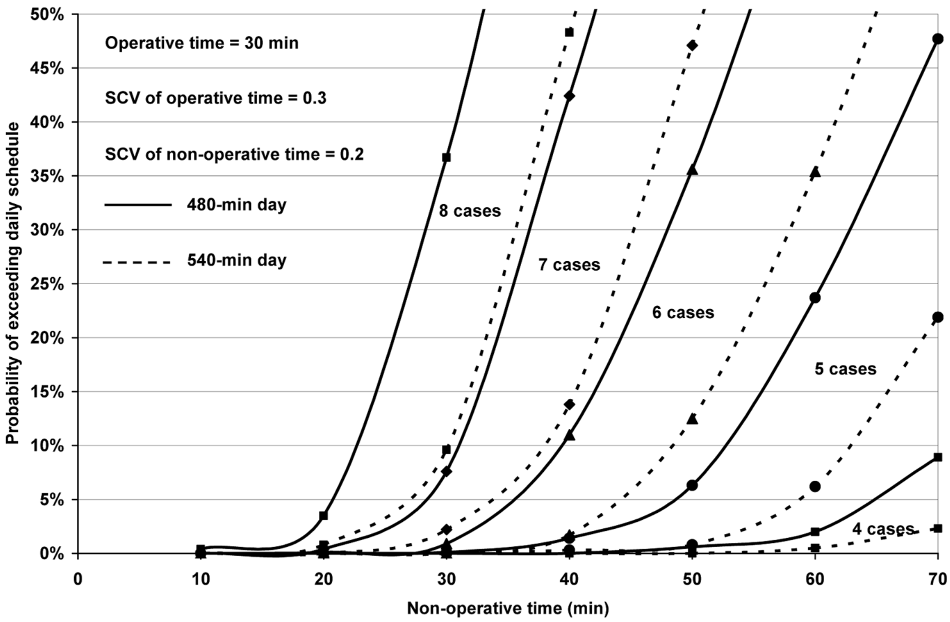

Figure 1 suggests that, given a mean non-operative time of about 48 minutes, a hospital that employs a nine-hour daily schedule can complete four cases with a mean operative time of 60 minutes in an OR with only a 5% probability of exceeding the scheduled hours. By contrast, should the hospital use an eight-hour day, it would have to achieve a 32-minute non-operative time to schedule all four cases without fear of exceeding the schedule. According to Table 5, this would be feasible if it employed all five methods for reducing non-operative time. If the hospital, using an eight-hour schedule, could only achieve a 40-minute non-operative time, it could still elect to schedule four cases, but it would have to expect to exceed the allotted schedule on 10% of days. For cases with 30-minute operative times (Figure 4), a reduction of non-operative time from 57 to 34 minutes would allow an institution using a nine-hour day to raise the number of cases from five to seven. This conclusion is consistent with results for Surgeon 4 in the Sandberg study (Sandberg et al., 2005a). By virtue of a reduction in non-operative time from 67 to 38 minutes, the surgeon was able to raise the number of cases from five to seven, while reducing the length of the operating day to fewer than 540 minutes.

Figure 2, showing the results for cases with operative times of 50 minutes, demonstrates the impact of the length of the day's schedule on the ability to add cases. For an eight-hour day, a hospital would have to reduce the non-operative to about 27 minutes if it wished to schedule a fifth case without exceeding a 5% probability of running over the allotted time. By contrast, for a nine-hour day, a hospital would only need to attain a non-operative time of 38 minutes to reliably schedule five cases.

Figures 1–4 are based on the assumption that the operative and non-operative time distributions are characterised by SCVs of 0.3 and 0.2 respectively. In general, as the SCVs increase, the non-operative times must be reduced to reliably accommodate a given number of cases. This emphasises the importance of establishing consistency in perioperative processes to sustain OR throughput.

The above quantitative results are based on the assumption that all cases have the same mean and variance of operative times. Because that is rarely the case, a simple decision support tool would be required to assist schedulers in effectively packing cases into the institution's daily schedule.

5 Estimated financial benefits of increasing OR throughput

Estimating the financial consequences of increased OR throughput is not straightforward. Firstly, it is important to recognise that if part or all of the economic impact is to be attributed to the incremental contribution margin from additional cases, the hospital must be confident that it will be able to increase its surgical caseload. The hospital may have cause for optimism if it believes that it will be able to attract some surgeons who currently prefer to operate at institutions where the ORs are more efficient. While recognising the practical importance of this complication, we will assume that the demand for short surgeries grows enough to consume the additional capacity created by reducing non-operative time. The second complication is the difficulty of translating the impact of additional cases into hospital-specific financial terms. This requires data about the hospital's contribution margin for the cases, which, in turn, must take into account the institution's own reimbursement arrangements with its payers. While this sounds straightforward in principle, it is less so in practice.[9]

A *generic estimate* of the incremental annual financial benefit *to the institution* of adding one short case per day into a single operating room, however, can be calculated as follows. Assume that the additional case has an operative time of 60 minutes and an ACT of 20 minutes (i.e. OR total process time = 80 minutes). For this situation, the daily incremental contribution margin realised by the institution would be $2000, assuming an incremental revenue of approximately $1500 per hour (Dexter et al., 2002; Macario et al., 2001; Wachtel et al., 2005). For a 250-day year, this leads to approximately $500,000. However, the contribution margin is based on the assumption that no new staff, technology or facilities are required to increase OR throughput. Thus, to correctly estimate the incremental margin, one must take them into account. In addition, it is again essential to stress that the addition of one case per day to an OR's schedule requires that the OR is used every day by a surgical service whose operative times are sufficiently short to add cases. If the assumption does not hold, the figure of $500,000 must be scaled down to reflect the fraction of days on which an additional case can be scheduled in advance, as well as the actual contribution margin generated by the procedure.

To estimate the impact of adding staff, we used a combination of US government data[10] and the assumption that the institution would spend an additional 30% for benefits. This leads to the following estimates of annual expenditure by job role:

Table 6 Estimates of annual expenditure by job role

Anaesthesiologist	$399,100
CRNA	$162,500
OR nurse	$68,900
Surgical Scrub	$48,100

Using the above data for the anaesthesiologist and nurse, we have estimated the incremental margin that could be achieved by some of the institutions whose work is summarised here if they were all operating in the USA. The results, shown in Table 7, suggest that the institution can profitably add the resources indicated, provided that:

- the additional procedures have OR total process times of at least 80 minutes
- the additional cases represent a previously unmet demand for surgery.

Estimating the impact of performing additional cases for individual hospitals becomes much more complicated when one considers local factors, rather than global estimates of the incremental contribution margin. The answer depends not only on the mix of cases performed and the speed and resource utilisation of its surgeons (Dexter et al., 1998, 2002; Macario et al., 2001; Resnick et al., 2005), but also on the hospital's staffing costs (Abouleish et al., 2003) and its reimbursement arrangements with its payers (Abouleish et al., 2004).

Table 7 Estimated annual incremental margin potentially realised by the hospital

Authors	*Δ Anaesthesiologist*	*ΔNurse*	*ΔExpense ($000)*	*ΔAverage cases/day*	*ΔRevenue ($000)**	*ΔMargin ($000)*
Hanss et al. (2005)	1	1	468	2	1000	532
Sandberg et al. (2005a)	0.5	2	337	0.8**	400	63
Smith et al. (2005)	0	0.9#	60	0.72##	360	300
Friedman et al. (2006)	0	0	0	0.6^	300	300

Notes: Calculations performed using US data for the hospital's contribution margin per OR hour and its expense for compensation and benefits of clinical staff.
* Based on $500,000 annual incremental revenue generated by adding one case, having an 80-minute OR Total Process Time, every day.
** Four additional cases per week (Sandberg, et al, 2005a).
\# Assumes 20% of the time of the specially designated PACU nurse in addition to the extra circulating nurse, prorated over the 15 days per month that the special OR is used.
\# # One additional case per day prorated over the 15 days per month that the special OR is used.
^ Hospital has opportunity to add three 80-minute cases one day per week.

It is difficult to test the validity of the results summarised in Table 7 in general. The sole exception is the Sandberg study (Sandberg et al., 2005a). In Table 7, the incremental margin for Sandberg, et al. (2005a) of $63,000, differs from the value of approximately zero reported in the primary study. Their detailed calculation, however, was based on the assumption of three additional cases per week, which is the performance attained during the period of their original study. However, we have consistently used a figure of four cases per week because, as mentioned above, it represents the current performance of the OR under study (Sandberg et al., 2005a; Seim and Sandberg, 2005). If the number of additional cases for the Sandberg study in Table 7 was reduced from 0.8 to 0.6, the incremental margin would be approximately $37,000 per year, a rather small value, not inconsistent with our estimate of zero. Recently this group has reported that their project, if efficiently scheduled, could sustain up to two additional cases per day with an incremental cost of $200 per case (Stahl et al., 2006), making the maximum incremental profit $650,000 per year for a single OR.

The foregoing analysis takes into account only the addition of clinical staff, not the addition of equipment or facilities. To replace a typical OR table and the cart used to transport patients to the OR by a system of mobile OR table tops would require an incremental investment ranging from $55,000 to $70,000, excluding installation (Personal communication, M. Walther, TRUMPF Medical Systems to DCK), or 11–14% of the incremental annual revenue generated by performing an additional short case each day. Detailed estimates of the incremental investment for induction and early-recovery rooms are beyond the scope of this article. However, our experience indicates that many hospitals have areas adjacent to their ORs that could be used for this purpose without new construction.

If an institution is able to increase its OR efficiency, but is unable to increase the number of cases, it may consider reducing the number of staffed ORs. For each OR whose clinical staff – conservatively assumed to consist of 0.5 anaesthesiologist, one CRNA, one OR nurse and one Surgical Scrub – has been redeployed, the institution has the potential to save annual OR expenses of approximately $480,000.

6 Conclusion

Operating room design and the perioperative processes around the OR have scarcely changed for the last 50 years. However, declining reimbursements and the requirement to support new technologies, provide an opportunity and an impetus to perform better. In response to this opportunity, several groups have challenged the notion that the key to OR efficiency is to create a square box with lights and a table and then staff it with exactly the same personnel mix as was provided in past decades. The operational results summarised here are impressive, and are likely to further improve when attention is also directed at eliminating the many annoying delays that plague perioperative systems (Sandberg et al., 2003). Moreover, the economic analysis, albeit generic, reveals that hospitals that devote themselves to reducing non-operative time can achieve substantial financial benefits. However, although the articles clearly indicate that achieving short non-operative times is technically feasible, they do not demonstrate that the required changes in process and technology are organisationally acceptable – or even appropriate – across an *entire* OR suite.

Demand for OR and procedural facilities appears to be increasing, and the popular response is to build new facilities. Building them, and then operating and staffing them using conventional models: serial processing with a surgical scrub, a circulating nurse, an anaesthesiologist who covers two ORs, a medically directed anaesthetist, and nursing resources up- and downstream seems unsustainable, given the current shortages in nursing and anaesthesia providers and the pressures to reduce healthcare costs. By contrast, commitment to increasing OR throughput in existing facilities by investing in the methods described here is the wiser strategy.

Acknowledgement

Departmental funding support was provided by the Massachusetts General Hospital Department of Anaesthesia and Critical Care (Boston, Massachusetts).

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Notes

1 We assume that the need to add capacity in other units to accommodate additional workload is at worst cost and revenue neutral.

2 For definitions of time intervals and milestones, see American Association of Clinical Directors Procedural Times Glossary (http://aacdhq.org?Glossary.htm, accessed 12/25/05).

3 Includes laparoscopic cholecystectomy, Nissen fundoplication, prostatectomy, nephrectomy and Heller myotomy.

4 For example, StatCom, Alpharetta, GA, USA.

5 Strictly speaking, Hanss et al. neither anaesthetised nor awakened patients in the OR. The three minutes represent the time consumed by the anaesthesia team in the OR during the non-operative interval.

6 We attribute the 12-minute turnover time of Smith et al. in part to the practice of opening up the instruments outside the OR.

7 Strictly speaking this line of reasoning is valid only for cases that require only a few minutes to apply dressings. In situations requiring a long time for dressings, which provide a more generous time margin for the anaesthesia team, the patient could be woken and ready to be moved out of the OR as soon as the dressings were complete. Our focus in this article, however, is on short cases, which would tend to have short times for the application of dressings and would force the anaesthesia team to be conservative in the timing of emergence.

8 Our assumed value for TOT is reasonable for short non-operative times, but low for long non-operative times. As a result, we overestimate T for long non-operative times.

9 In fact, of the studies considered here, only Sandberg et al. (2005a) describe a detailed financial analysis of the economic impact of their interventions.

10 Annual salary figures: Anaesthesiologist: www.bls.gov/oco/content/ocos074.stm#related; for RNs: www.bls.gov/oco/ocos083.htm#earnings; Scrub Tech: www.bls.gov/oco/print/ocos106.htm] and CRNAs: recent advertisements for CRNA positions.

Appendix

Table A-1a Summary of articles on impact of non-operative time reductions resulting from redesigning the perioperative system – primarily general anaesthesia

Authors	*Objective of study*	*Process investigated*
Hanss et al. (2005)	Evaluate the impact of overlapping induction (OI) on OR productivity.	Next patient is anaesthetised and positioned in separate induction area; process begins while previous patient still in the OR. Following surgery, patient, still under anaesthesia is moved to a pre-PACU, early recovery area. Process was tested in 2 and 3 ORs.
Torkki et al. (2005)	Assess the impact of anesthetising patients before they reach the OR on (a) ACT and TOT and (b) the number of the day's cases.	One induction area, serving 4 ORs, is staffed by one anaesthesiologist and two nurses. For one of the ORs only, induction is performed in parallel with the previous procedure, and the team inducing anaesthesia follows its patient to the OR and remains there for the procedure. Following emergence in the OR, three nurses accompany the patient to the PACU; one takes a break, while the others fetch the next patient and participate in the next induction.
Sandberg et al. (2005a)	Assess the impact of process, technology and staffing modifications on TOT + ACT and the number of cases performed in one day in a single OR.	Patients are brought to the induction room, adjacent to the OR, where they are examined and anaesthetised while the OR is being set up. When the OR is ready, the patient is transported on a mobile OR table top to the OR. As the surgery nears completion a 'perioperative' nurse comes to the OR to receive post-anaesthesia report. After emerging in the OR, the patient is moved to the early recovery room, also adjacent to the OR, where the perioperative nurse assumes care. Subsequently the patient is transferred to a gurney and moved to the PACU by the perioperative nurse.
Harders et al. (2006)	Reduce ACT + TOT using mobile table tops and a modified process without recourse to special facilities or additions to staff.	Next patient is placed on mobile table top in pre-op area for IV insertion, etc. and for encounters with anaesthesiologist and surgeon. Patient is brought to OR by nurse anaesthetist for induction by the anaesthesiologist, who covers 2 ORs, and the nurse anaesthetist. Following surgery, anaesthesiologist transports patient to PACU while nurse anaesthetist prepares medication and equipment for next patient.
Cendan et al. (2006)	Reduce TOT without the use of (substantial) additional staff and without using additional technology or special facilities	Process modifications include summoning the OR Charge Nurse to the OR to cover for the circulating nurse (CN) who goes out to check in the next patient in the pre-operative area and obtains medications for the next case. Electronic signature and document transmission used to eliminate need for CN to deliver printed documentation to PACU. Anaesthesia technician is assigned some of the turnover tasks previously performed by the anaesthesiologist

Table A-1b Summary of articles on impact of non-operative time reductions resulting from redesigning the perioperative system - primarily general anaesthesia

Authors	*Comparison process*	*Duration of study*	*Types of patients*	*Procedures*
Hanss et al. (2005)	Anaesthesia start in the induction room begun only after anaesthesia finish for previous patient; positioning also in induction area; emergence in OR, followed by transfer to PACU.	Total of 60 days: 15 days of OI followed by 15 days of Control in 2 ORs; repeated with 3 ORs.	A pool of waiting inpatients who can be called if time for an additional case is created by reducing Non-Operative Time.	'Visceral' surgeries – thoracotomies, upper and lower laparotomies, pediatric surgery.
Torkki et al. (2005)	Induction in the OR.	Five-week prospective study using the comparison process followed by 4 weeks with the new process.	Urgent and emergent trauma cases.	Urgent and emergent trauma procedures.
Sandberg et al. (2005a)	Patient is prepared but not anaesthetised in an area adjacent to the OR. Following emergence in the OR, patient is transported to the PACU, accompanied by the anaesthesiologist.	Results primarily based on 14-month study ending October 31, 2003, with control data for some surgeons from a 12-month period ending August 31, 2002.	Elective surgery for a mix of ambulatory patients and patients admitted to the hospital on the day of surgery, with a few urgent inpatient cases.	Broad collection of open and minimally invasive, frequently technically complex, elective surgeries with average operative time of about 90 minutes.
Harders et al. (2006)	Does not use mobile OR table tops and has very limited parallelism: Patients are brought to OR by Circulating Nurse; cleanup begins only after the patient has left the OR.	Approximately 3 months.	Primarily ambulatory patients.	Mostly cases whose operative time did not exceed 2 hours.
Cendan et al. (2006)	CN stays in the OR until the patient leaves, only then dropping off any pathology samples, picking up medications for the next case and checking in the next patient in the preoperative holding area. CN also responsible for delivering printed operative record to PACU.	Baseline observation period of approximately 6 weeks; pilot study of approximately 4 weeks used to try out concepts with one surgeon and one anaesthesiologist; large-scale study of approx. 3 months in 4 ORs.	Selection based on operative time.	Short- to medium-duration cases, offering opportunities for multiple turnovers every day.

Table A-1c Summary of articles on impact of non-operative time reductions resulting from redesigning the perioperative system – primarily general anaesthesia

Authors	*Participating professional staff*	*Incremental staff*	*Special facilities, equipment*	*Additional important facts*
Hanss et al. (2005)	Information not provided.	Extra anaesthesiologist and nurse assigned to perform inductions; each OR staffed by an anaesthesiologist and nurse.	Induction area; early recovery area; mobile OR table tops to permit transport of anaesthetised patients.	Authors draw attention to concept of performing in the OR only those activities that truly demand the OR environment.
Torkki et al. (2005)	Information not provided.	Additional team of one anaesthesiologist and two nurses.	Area set aside for induction outside the OR; mobile table tops (personal communication, Dr Riita Marjamaa to DCK.)	None.
Sandberg et al. (2005a)	Three general surgeons, 1 gynaecologic surgeon, and 1 urologist.	Perioperative nurse; Anaesthesiologist with responsibility for 1 OR rather than the normal 2 ORs; additional circulating nurse for many cases.	Special facilities as described above; mobile table tops with monitors below surface to permit continuous monitoring.	Moving activities that do not require the OR to a new location and running them in parallel with other processes allows them to occur at a natural pace while the overall process is accelerated.
Harders et al. (2006)	Twenty three surgeons, 13 anaesthesiologists, and 11 nurses.	None. Anaesthesia team makes the greatest adjustment by dividing responsibilities during non-operative interval.	Mobile table tops that eliminate the need to transfer the patient from one surface to another before and after surgery	Synchronising signals are important because of extensive parallel processing. Signals include early warning to housekeeping staff and a ‘room ready’ signal from Circulating Nurse to Nurse Anaesthetist.
Cendan et al. (2006)	Four surgeons who performed more than 25 cases each during large-scale study period.	Almost none: Charge nurse covered for circulating nurse for about 15 minutes near end of each procedure.	None.	Synchronising signals are used to: (1) alert CN of the next patient’s arrival in preoperative holding area; (2) alert anaesthesia technician of a pending turnover.

Table A-1d Summary of articles on impact of non-operative time reductions resulting from redesigning the perioperative system – primarily general anaesthesia

Authors	*Results – Times (min)*	*Results – Additional cases*	*Results – Economic impact*	*Improvement opportunities*
Hanss et al. (2005)	ACT + TOT: 43 ± 23 → 28 ± 18 (Mean ± SD) TOT: 38 ± 24 → 25 ± 15 NST: 68 ± 26 → 57 ± 18	For 3 ORs, found that 2 additional cases per day could be performed, while for 2 ORs, the average was only 0.2 additional cases per day.	Authors calculate an index for each type of surgery to determine whether an additional case is worth scheduling.	
Torkki et al. (2005)	Total time savings ≈ 52 min. Sources: elimination of anaesthesia prep = 20 min; reduction of delays = 18 min; reduction in surgical time = 9 min.	Number of cases per day: 2.3 → 3.3	Not discussed.	
Sandberg et al. (2005a)	ACT + TOT: 67 (64–70) → 38 (35–40) (Mean (95% CI)) TOT: 36 (34–38) → 22 (21–23) OR Anaesthesia time: 13 (12–15) → 3 (2–3) OR emergence time: 13 (12–15) → 10 (9–11)	Surgeon 1: no change Surgeon 2: eliminated 1 hr of over-utilised OR time Surgeon 3: about 1 additional case per day Surgeon 4: about 2 additional cases per day; finish 1 hour earlier	Global net margin unchanged because incremental revenues generated by performing more cases were offset, primarily by higher staffing cost.	
Harders et al. (2006)	ACT + TOT: 65.3 ± 21.7 → 42.2 ± 12.9 (Mean ± SD) TOT: 42.8 ± 21.7 → 26.4 ± 11.2 OR Anaesthesia time: 11.7 ± 6.2 → 8.5 ± 4.3 OR emergence time: 10.2 ± 7.4 → 8.4 ± 5.8	Information not furnished.	Not stated.	Authors state that high percentage of process-related delays suggest further reductions, particularly in TOT, are anticipated
Cendan et al. (2006)	TOT: 43.7 ± 23.3 → 27.7 ± 14.6 (Mean ± SD)	Cases per day Surgeon A: 1.68 → 2.48 Surgeon B: 2.27 → 3.25 Surgeons C and D (D follows C): 1.50 → 1.88		

Table A-2a Summary of articles on impact of non-operative time reductions resulting from redesigning the perioperative system – primarily regional anaesthesia

Authors	*Objective*	*Process investigated*	*Comparison process*	*Duration of study*
Friedman et al. (2006)	Assess the impact on number of cases that can be performed by parallel processing	While the OR is being turned over, sedation and local block are administered in an induction area, set aside within the pre-op area. Prepping completed in the OR.	Sedating, administering local anaesthesia and prepping in the OR after it is turned over. The reference process was run for 2 months prior to the study and was also used in a second OR on one afternoon per week during the study by the same surgeon.	Baseline for two months; study for 12 weeks.
Smith et al. (2005)	Design a process capable of a significant reduction in TOT and TOT+ACT.	In parallel with OR breakdown and setup, spinal anaesthesia administered in an 'induction room environment', staffed by 2 circulating nurses who alternate patients. Following surgery, a specially designated PACU nurse comes to the (single) OR to transport patient to PACU. If there are medical concerns, a member of the anaesthesia team accompanies the patient to the PACU.	The standard process consists of administering anaesthesia in the OR and having a member of the anaesthesia team accompany the patient to the PACU.	10 weeks, with the process followed one day per week.

Table A-2b Summary of articles on impact of non-operative time reductions resulting from redesigning the perioperative system – primarily regional anaesthesia

Authors	*Types of patients*	*Procedures*	*Participating staff*	*Incremental staff*	*Special facilities, equipment*	*Other important facts*
Friedman et al. (2006)	Ambulatory patients.	Hernia repairs – inguinal, umbilical and ventral.	Surgeon, resident, scrub tech, circulator, sedation nurse. In contrast to the practice followed in the reference process, the team stayed together throughout the day.	None.	Special slot in pre-operative holding area.	
Smith et al. (2005)	Ambulatory patients.	Hip and knee replacements.	Five of 58 orthopaedic surgeons; most of the orthopaedic nursing staff.	Two circulating nurses; specially designated PACU nurse (who fetches patients from OR); experienced person from environmental services.	Area set aside for administering spinal anesthetic; Pyxis machine in the OR; walkie-talkies; instrument tables set up in advance by surgical technologists and covered.	Following each day during which the process was tested, participants were interviewed and process improvements, if deemed valuable, were rapidly implemented.

Table A-2c Summary of articles on impact of non-operative time reductions resulting from redesigning the perioperative system – primarily regional anaesthesia

Authors	*Results – Times (min)*	*Results – Additional cases*	*Results – Economic impact*	*Improvement opportunities*
Friedman et al. (2006)	Sedate, block and prep: 17.3 ± 7.8 (concurrent control) and 19.6 ± 5.3(historical control) → 7.7 ± 3.1 for the s tudy group (mean ± SD) TOT: 24 ± 0 (concurrent control) and 32.6 ± 30 historical control) → 17.8 ± 10.8 No significant change in operative times The effective change in non-operative time ≈ 21 minutes, yields a reduction of about 30% in OR Total Process Time	The surgeon was ultimately able to perform all of his cases on one day, rather than taking one and a half days for the same number of cases. Improvement in TOT is attributed to improved team work by the coherent team. A satisfaction survey showed that patients were pleased with the process.	No data are adduced. The team freed up half of an OR day per week.	None discussed. However, authors claim to be seeking surgeons who have large and consistent case volumes of short cases and who could take advantage of the method.
Smith et al. (2005)	TOT: 30 → 12 Patient time in room to incision: 52 → 32 For more than half of turnovers, patient out of OR to next incision = 35	One additional case per day		

Abbreviations: ACT: anaesthesia controlled time, OR: operating room, PACU: post-anaesthesia care unit, SD: standard deviation, TOT: turnover time