Configuring Surgical Instrument Trays to Reduce Costs

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Abstract: Configuring Surgical Instrument Trays to Reduce Costs

Most research on operating room (OR) management focuses on issues of work flow, time and schedule management, but not on the management of OR supplies. This is despite reports that, in perioperative services, supply expenses exceed non-physician labor expenses. Surgical instruments are an important category of OR inventory. They are expensive to buy and expensive to maintain. The sheer volume and variety of instruments introduces considerable complexity in ensuring that the right instruments are available at the right time. Surgical instruments are usually stored and delivered to an OR as procedure-specific sets of trays (e.g., mediport insertion tray, suture tray, hernia tray, etc.), with multiple instruments included in a single tray. Clearly, the batching (or kitting) of surgical instruments has many benefits, yet the actual tray design is a complex combinatorial problem. The design of trays affects the costs of owning, maintaining, and using both the trays and the instruments. Because the trays are used by multiple surgeons trained at different institutions, they often include surgeon-specific instruments. The inclusion of such instruments has been shown empirically to contribute to OR inefficiency.

The data for this study was collected at a midsize U.S. hospital, where seventeen surgeons in four surgical services perform approximately 4,000 procedures each year. We collaborated with surgeons, OR nurses and the materials management (ORMM) staff at the hospital. One of the authors of this study is a senior general surgeon and a hospital board member. Using the hospital data, we conducted numerical experiments for a range of reasonable cost parameters. Our results suggest that costs can be reduced significantly: \$10K-\$17K per year for just two surgeons. Furthermore, as the number of surgeons grows, the potential for savings increases.

Based on our numerical experiments and field observations, we suspect that ORMM managers underestimate the cost of reprocessing extra instruments and overestimate the holding costs of inventory. This bias leads to a smaller variety of trays with more instruments and, therefore, larger costs, due to reprocessing of extra instruments. Optimizing the configuration of surgical trays can increase surgeon satisfaction without increasing ORMM workload. The time saved for staff in reprocessing instruments can be spent managing a larger variety of trays, which will result in higher satisfaction for surgeons.

We demonstrate that optimal tray configurations depend on surgery schedules and conclude that it is highly unlikely that low-cost tray configurations can be created without the aid of a decision support module. We propose a linear integer programming formulation to optimize tray configurations for operating rooms, which takes into account physician preferences and schedules. The number of decision variables and constraints in our formulation grows exponentially with the number of surgeon-procedure pairs. We propose a modified formulation which is solved quickly, yet performs very well compared to full formulation.

Configuring Surgical Instrument Trays to Reduce Costs

1. Introduction

Most studies of operating room (OR) management focus on issues of work flow, time and schedule management, but not on management of OR supplies (Cardoen, Demeulemeester, & Beliaen, 2008; Park & Dickerson, 2009). We are aware of but a few papers (Machline, 2008; Reymondon, Pelletc, & Marcon, 2008; Wolbers, 2008) that deal with materials management in an OR. This is despite reports that, in perioperative services, *supply* expenses exceed labor expenses of non-physician staff (Park & Dickerson, 2009). Our research on management of surgical instruments is motivated by the analysis of a midsize hospital in upstate New York, where seventeen surgeons in four surgical services perform approximately 4,000 procedures each year. We collaborated with surgeons, OR nurses, and the materials management team at the hospital. One of the authors of this paper is a senior general surgeon and a member of the hospital board.

In U.S. hospitals, materials management staff cleans, disinfects, and sterilizes surgical instruments between surgeries. Instruments are usually stored and delivered to an OR as procedure-specific trays (e.g., suture tray, hernia tray, etc.), with multiple instruments included in a single tray. As noted by Machline (2008), there are many advantages to organizing instruments into trays: reliability in providing the needed instruments for a surgery; speed of instrument delivery in an emergency situation; reduction in labor hours needed to assemble the instruments because tools from a tray are processed together; and tighter control over the inventory, because it is easier to notice a missing or damaged instrument in a small set.

Normally, surgery trays, designed for use for a particular surgery, are used by multiple surgeons trained at different institutions. Thus, frequently, surgeon-specific instruments are added to the procedure trays. Surgeons want to know that the instruments they may need will be readily available. At the same time, surgeons prefer not to have unneeded instruments during surgery. It has been shown empirically that the inclusion of surgeon-specific instruments to trays used by all surgeons contributes to OR inefficiency by slowing down surgeries (Farrokhi, Gunther, Williams, & Blackmore, 2013; Stockert & Langerman, 2014). There is a tension between the materials management group's objective of keeping down the cost of instruments and variety of trays and the surgeons' convenience.

In this study, we explore the connection between surgery schedules, the organization of surgical instruments into trays, and the level of inventory that a hospital needs to maintain to safely support a given OR schedule. Reymondon et al. (2008) considered a problem of tray composition with the objective of minimizing reprocessing and storage costs. They proposed a mathematical programming formulation and discussed computational challenges arising from the problem's size. We advance this research by:

a) Proposing a modified linear integer programming formulation,

b) Proposing a heuristic methodology for tray configuration and numerically demonstrating the heuristic's excellent performance, and

c) Demonstrating cost savings that can be achieved by optimizing tray configuration using data from a midsize U.S. hospital (we show that savings increase significantly with the number of practicing surgeons and demonstrate that optimal tray configurations depend on surgery schedules; therefore we conclude that it is highly unlikely that low-cost tray configurations can be created, or updated without the aid of a decision support module).

Section 2 of this paper discusses the trade-offs involved with various tray configurations. Section 3 provides the mathematical programming formulation and a heuristic for handling a large problem. Our numerical results are presented in Section 4, and Section 5 concludes.

2. Model Development: Discussion of the Practice for One General Surgeon

One general surgeon from our data set performs approximately 270 procedures per year. The seven most frequently performed procedures are listed as column headings in Table 1. For the year we collected data, Table 1 lists the number of times each procedure was performed, the maximum number of times each procedure was performed in a single day, the total number of instruments needed for each procedure, and the approximate acquisition cost of these instruments.

One possible way to organize the instruments is to have a separate tray type for each procedure performed by this surgeon, i.e., seven types of trays. This arrangement will lead to high inventory costs because there will be multiple copies of instruments that are used in multiple procedures. Another feasible way to organize the instruments is by their patterns of use. Table 1 shows that the instruments can be grouped into eighteen instrument sets, with each set utilized in a distinct set of procedures. Having more types of trays saves on instrument acquisition and inventory costs; however, there are costs associated with using more trays during a procedure, e.g., the cost of inspecting the wrapping of each tray for sterility at the start of surgery, and the cost of sorting instruments into the correct trays after reprocessing. This sorting is not a trivial task — many instruments look similar, and some materials management departments create picture books to help technicians identify and correctly sort the instruments.

In both types of tray configuration considered so far, no extra instruments are opened (unwrapped) during a surgery. Costs associated with handling unneeded instruments include the cost of cleaning and sterilizing, as well as the cost of wear and tear — the instruments deteriorate with repeated washing and sterilization. Unneeded instruments may also slow down the OR team, as they must search for a particular instrument among a larger set. For certain procedures, extra instruments mean additional time in the OR, as the instruments have to be counted before and after the procedure. For additional discussion of OR cost and time implications of extra instruments, see (Farrokhi et al., 2013; Stockert & Langerman, 2014).

Table 1. Instrument Preferences and Annual Procedure Statistics for One General Surgeon

	Procedure						
	mediport insertion	*excision of small lesion*	*lap appen-dectomy*	*lap cholecys-tectomy*	*lap ventral hernia repair*	*open hernia repair*	*bowel resection*
Times in One Year	17	105	9	70	7	55	7
Max Times in a Single Day	2	4	1	2	1	4	1
Num of Instruments	38	39	60	63	63	65	99
Cost of Instruments	$540	$551	$9,447	$8,501	$10,481	$1,196	$2,533

	By Pattern of Use									
Instruments Grouped By Use Patterns	*mediport insertion*	*excision of small lesion*	*lap appen-dectomy*	*lap cholecys-tectomy*	*lap ventral hernia repair*	*open hernia repair*	*bowel resection*	**Number of Instru-ments**	**Cost of Instru-ments**	**Number of Trays Needed in a Day**
1	X	X	X	X	X	X	X	12	$195	7
2	X	X		X	X	X	X	1	$6	6
3	X	X	X	X	X			4	$53	7
4	X	X				X	X	12	$167	6
5	X	X				X		3	$25	6
6		X				X		1	$11	5
7			X	X	X	X	X	10	$113	4
8				X	X	X	X	1	$17	4
9	X	X						6	$94	5
10			X	X	X		X	12	$180	3
11			X	X	X			19	$6,860	3
12				X	X			1	$1,010	2
13				X			X	2	$27	2
14				X				1	$40	2
15						X	X	25	$663	4
16			X		X		X	1	$512	2
17			X		X			2	$1,535	2
18							X	23	$654	1

In considering how to configure instrument trays for surgeries, it is important to recognize the various costs associated with different tray configurations: holding costs per tray, holding costs per instrument, usage costs per tray (for opening trays), and usage costs per instrument (for counting instruments in the tray, for having unneeded instruments in the tray, and for reprocessing instruments – cost of washing, sorting, sterilizing, and wear and tear).

3. The Mathematical Programming Formulation

The decision problem is to find a configuration of instrument trays that minimizes holding and usage costs while satisfying instrument availability requirements arising from surgeons' preferences and schedules. Let S be the set of surgeons, and P^s be the set of procedures performed by surgeon $s \in S$. Let $P = \bigcup_{s \in S} P^s$ be the set of all relevant procedure-surgeon combinations, and I be the set of all instruments. To streamline terminology, from here on, we will refer to a *procedure-surgeon* combination simply as a *procedure*. Let $r_p^i \in \{0,1\}$ be an indicator variable, with $r_p^i = 1$ indicating that instrument i is required for procedure p, and with $r_p^i = 0$ that it is not.

We describe a tray type in two distinct ways: (*a*) a set of instruments included in the tray, and (*b*) a set of procedures supplied with this type of tray. We assume that there is a unique tray type associated with a set of procedures, and thus there cannot be multiple tray types that are supplied for the same exact set of procedures but that include different sets of instruments.

It is possible to formulate a tray configuration solution where different sets of tray types are used for the same procedure, for example, on different days. However, the assumption that a procedure is always supplied with the same set of trays types reflects current OR practice, where hospital information systems store a single collective surgeon preference, not a set of alternatives.

Define the set of tray types $T = \{\boldsymbol{t} \in \{0,1\}^{|P|}, \boldsymbol{t} \neq \boldsymbol{0}\}$, i.e., all the non-empty subsets of procedures; thus a tray of type $\boldsymbol{t}$ is supplied to a procedure p, means $t_p = 1$. Mathematically, the problem of organizing surgical instruments into trays can be expressed as minimizing per-period cost:

$$\min_{\boldsymbol{z},\{\boldsymbol{x^t}\}} \sum_{\boldsymbol{t}\in T} c^{\boldsymbol{t}} z^{\boldsymbol{t}} + \sum_{\boldsymbol{t}\in T} \sum_{i\in I} c_i^{\boldsymbol{t}} x_i^{\boldsymbol{t}} \tag{1}$$

subject to:

$$x_i^{\boldsymbol{t}} \leq z^{\boldsymbol{t}}, \qquad \forall i \in I, \forall \boldsymbol{t} \in T$$

$$\sum_{\boldsymbol{t}\in T} t_p x_i^{\boldsymbol{t}} \geq r_p^i, \forall i \in I, \forall p \in P$$

$$z^{\boldsymbol{t}} \in \{0,1\}, \forall \boldsymbol{t} \in T$$

$$x_i^{\boldsymbol{t}} \in \{0,1\}, \forall i \in I, \forall \boldsymbol{t} \in T.$$

The two decisions being made simultaneously in (1) are: (*a*) what types of trays to use ($z^{\boldsymbol{t}}$), and (*b*) what instruments to assign to each type of tray($x_i^{\boldsymbol{t}}$) that is used. The constraint $x_i^{\boldsymbol{t}} \leq z^{\boldsymbol{t}}$ allows the instrument i to be included in a tray type $\boldsymbol{t}$ only if the tray type is actually used. Coefficients $c^{\boldsymbol{t}}$ and $c_i^{\boldsymbol{t}}$ represent respectively the per-period cost of holding and using a tray of type $\boldsymbol{t}$, and the cost of holding and using instrument i in trays of type $\boldsymbol{t}$.

The cost of using and holding trays of type $\boldsymbol{t}$ is equal to:

$$c^{\boldsymbol{t}} = \left(w_0 \frac{k^{\boldsymbol{t}}}{m^{\boldsymbol{t}}} + h_0\right) m^{\boldsymbol{t}} = w_0 k^{\boldsymbol{t}} + h_0 m^{\boldsymbol{t}}, \tag{2}$$

where $m^{\boldsymbol{t}}$ is the inventory of trays of type $\boldsymbol{t}$, $k^{\boldsymbol{t}}$ is the total number of times trays of type $\boldsymbol{t}$ are used per period, h_0 is the per-period per-tray holding cost, and w_0 is the usage cost per-tray per-performed-procedure. We assume that h_0 and w_0 are identical for all tray types. The cost $c_i^{\boldsymbol{t}}$ for instrument i in tray type $\boldsymbol{t}$ is analogous: $c_i^{\boldsymbol{t}} = w_i k^{\boldsymbol{t}} + h_i m^{\boldsymbol{t}}$.

The value of $k^{\boldsymbol{t}}$ is found from the average number of times a tray of type $\boldsymbol{t}$ was used during a single day as:

$$k^{\boldsymbol{t}} = \left(\sum_{p \in P} t_p \sum_{d \in D} f_{pd} \right) \Big/ D \ \ \forall \boldsymbol{t}, \tag{3}$$

where f_{pd} is the number of times procedure p was performed on day $d \in D$. We also use historical scheduling data to determine the required inventory of trays as:[1]

$$m^{\boldsymbol{t}} = \max_{d \in D} \left\{ \sum_{p \in P} f_{pd} t_p \right\} \ \forall \boldsymbol{t}. \tag{4}$$

Here, we assume that no instrument can be used more than once a day. This is broadly reflective of hospital practice. Even when expedited, cleaning and sterilizing of instruments takes a significant amount of time. Integrating surgery schedules with tray availability could reduce inventory costs for the hospital. For example, if instead of performing five cataract surgeries in a single day on a given week, an eye surgeon were to operate five days a week, every day performing a single surgery, then only a single eye surgery tray would be needed. Such surgery scheduling, however, would not be acceptable to surgeons; surgery times are normally allocated to different surgical services in blocks. Therefore, we assume that the surgery schedule is a given.

The computational size of (1) grows exponentially with the number of procedures: the total number of decision variables is $(2^{|P|} - 1)(|I| + 1)$. The number of constraints is $|I|(|P| + 2^{|P|} - 1)$. Therefore, we introduce a heuristic methodology based on grouping instruments together and limiting the types of trays in the consideration set. Let $\boldsymbol{r}^i \in \{0,1\}^{|P|}$ be the requirements vector indicating which procedures require instrument i, i.e., $r_p^i = 1$ if procedure p requires instrument i. We define V to be the set of all *unique* vectors $V = \{\boldsymbol{r}^i, i \in I\}$. We define a subset of tray types T', which is formed by augmenting V with the unit vectors, representing procedure-specific tray types: $T' = V \cup \{\boldsymbol{e}^p \in \{0,1\}^{|P|} : p \in P\}$. Because some instruments will have the same requirements vectors, we define $I(\boldsymbol{v}) = \{i : \boldsymbol{r}^i = \boldsymbol{v}\}$ to be the instruments that all have the same requirements pattern $\boldsymbol{v}$.

Now our heuristic methodology is the following restricted formulation:

$$\min_{\boldsymbol{z}, \{\boldsymbol{x}^{\boldsymbol{t}}\}} \sum_{\boldsymbol{t} \in T'} c^{\boldsymbol{t}} z^{\boldsymbol{t}} + \sum_{\boldsymbol{t} \in T'} \sum_{\boldsymbol{v} \in V} c_{\boldsymbol{v}}^{\boldsymbol{t}} x_{\boldsymbol{v}}^{\boldsymbol{t}} \tag{5}$$

subject to:

$$x_{\boldsymbol{v}}^{\boldsymbol{t}} \le z^{\boldsymbol{t}}, \qquad \forall \boldsymbol{v} \in V, \forall \boldsymbol{t} \in T'$$

[1] Using *historical* data may not account for very rarely occurring combinations of procedures performed on the same day. One alternative is to use simulation to generate a very long-term schedule based on the OR block schedule, historical data on the relative frequency of performed procedures, and the scheduled duration for each procedure.

$$\sum_{\boldsymbol{t}\in T} t_p x_{\boldsymbol{v}}^{\boldsymbol{t}} \geq r_p^{v}, \forall \boldsymbol{v} \in V, \forall p \in P$$

$$z^{\boldsymbol{t}} \in \{0,1\}, \forall \boldsymbol{t} \in T'$$

$$x_{\boldsymbol{v}}^{\boldsymbol{t}} \in \{0,1\}, \forall \boldsymbol{v} \in V, \forall \boldsymbol{t} \in T',$$

where $c_{\boldsymbol{v}}^{\boldsymbol{t}} = \left(\sum_{i\in I(\boldsymbol{v})} w_i\right)k^{\boldsymbol{t}} + \left(\sum_{i\in I(\boldsymbol{v})} h_i\right)m^{\boldsymbol{t}}$. The decision variables $x_{\boldsymbol{v}}^{\boldsymbol{t}}$ represent the decisions on the assignment to a tray of type $\boldsymbol{t}$ of all the instruments with the requirement pattern $\boldsymbol{v}$. Constraining the solutions in this way makes it impossible to create trays comprising instruments that are never used together in one procedure. Such trays could be desirable if the holding cost of trays is high and creating one tray to be used for several procedures is cheaper than creating separate trays. The trade-off is the extra usage costs from unneeded instruments, thus a common tray with instruments that are not used together could make sense only for rarely performed procedures that use only a few instruments.

The number of decision variables in (5) is $(|V| + |P|)(|V| + 1)$, and the number of constraints is $|V|(|V| + 2|P|)$. So the problem size becomes quadratic in $|V|$, rather than exponential in $|P|$. There is an upper limit on the cardinality of the set V, $|V| \leq min\{2^{|P|} - 1, |I|\}$, and for realistic scenarios the size of $|I|$ is small compared to $2^{|P|}$.

4. Numerical Case Study

4.1. Heuristic Performance Based on Randomly Generated Problems

We tested the performance of (5) relative to (1) using the historical schedules of procedures and instrument acquisition costs shown in Table 1. The values for the holding costs of instruments and trays, as well as the values for per-use costs, were based on reasonable estimates, which we discuss later in Section 4. We generated 500 random instances of instrument preferences and used the 2013 version of IBM ILOG CPLEX to solve both the IPs (1, 5) and the relaxed LP versions of the same formulations. These were small problems where it was possible for us to solve (1) to provide evidence of how well (5) performs. We ran the code on a desktop PC running the Windows 7 operating system. The solution for each experiment computed in less than one second.

Interestingly, in eighteen out of 500 cases, the solution found via integer formulation (5) resulted in *lower* cost than the solution to the full IP (1). In all eighteen of these cases, there was a very large gap between the optimal solutions to (1) when the integer constraint was relaxed and when it was enforced. For the other 482 cases the heuristic also performed very well. The cost obtained as the solution to (5) was, on average, only 1.9% higher than the minimum cost found using the full formulation (1).

4.2. Description of Numerical Experiments with Actual Surgeon Requirements

We conducted three sets of numeric experiments comparing a benchmark solution based on the current tray configuration in the hospital with an optimized configuration. The first set of experiments considered tray configurations optimized for the preferences and the schedule of a single surgeon (Table 1). In the two other sets of experiments, we optimized tray configuration to account for preferences of two general surgeons. To do that, we obtained preference information from a colleague of our surgeon co-author. In the first of the two cases, we assumed that the two surgeons had historical schedules that were identical in every respect, except that the two surgeons performed surgeries on different days, i.e., the schedules did not overlap. In the second case, we assumed that the surgeons do operate on the same days throughout the year. We generated the schedule using bootstrapping: randomly picking daily schedules for the first and the second surgeon from the original daily schedule list we used in the previous section. Because the second schedule was created via bootstrapping, the annual number of performed procedures was not identical to the number of procedures in the first schedule (568 vs. 540).

To ensure that our experiments used reasonable values, we obtained data on instrument acquisition costs. Denote this cost for instrument i as β_i. The instrument cost data is summarized across instrument-use patterns in Table 1. In our data set, instrument acquisition costs varied between \$5 and \$1,000, with a median of \$16. We used a holding cost of 20 percent per year. Using reprocessing and staffing data from the hospital, we estimated the cost of cleaning and sterilizing instruments at \$1.05 per instrument per use.[2] Depending on interpretation, the instrument replacement budget constituted between 5 percent and 29 percent of the cleaning and sterilizing budget, so to model a comparable cost of replacement, we assumed that an instrument is replaced after 500 uses: $w_i = 1.05 + \beta_i/\bar{u}$ where $\bar{u} = 500$.

Within each experiment set, we varied the difficult-to-estimate values of h_0 and w_0. We tested our findings by considering annual per-tray holding costs of $\{\$50, \$100, \$500\}$; at 20 percent per year, these correspond to tray acquisition costs of $\{\$250, \$500, \$2500\}$. Our experiments used a cost w_0 from the set $\{\$10, \$100\}$. This cost models the cost of opening and inspecting a tray for sterility and subsequent sorting of instruments into trays after washing.

In evaluating our results, we considered the current practice in the hospital as the benchmark. The actual current configuration includes instruments needed by many surgeons. To make the comparison fair, we considered as the benchmark configuration a modified version of configuration that minimizes (1). In formulation (1) we consider the full set of $(2^{|P|} - 1)$ tray-to-procedure-mappings as feasible. In finding the benchmark tray configuration, we limited the feasible tray-to-procedure mappings to the four tray types that are currently used in the hospital: One tray type for both mediport insertions and excisions of small lesions; a laparoscopic tray for the three laparoscopic procedures; a tray for open hernia repair and bowel resection, and a fourth tray, a “deep abdominal” tray, used only for bowel resection.

[2] This estimate is based on the number of employees in OR materials processing, the number of procedures performed per year, and the average number of instruments per procedure: (7 employees *\$15 per hour * 2,000 hours per year per employee)/(4,000 procedures per year * 50 instruments per procedure).

4.3. Computations and Results

In the course of our research, we identified aspects of tray configuration that are important to surgeons, operating rooms nurses, and materials management personnel. These include: total cost of instrument inventory, number of tray types, total number of trays, average number of trays opened during a procedure, and average number of unneeded instruments handled during a procedure. We use these attributes to summarize the results of the experiments (Table 2).

Table 2. Summary of Numerical Experiments

Optimization Parameters		**Annual Cost**			**Specifics of the cost minimizing configuration**				
Annual per-tray holding cost	**Tray handling cost, w_0**	**Benchmark**	***Minimum***	**Savings relative to benchmark**	**Total cost of instr. in stock**	**# of tray types**	**# of trays in invent-tory**	**Avg. # of trays opened per proc.**	**Avg. # of extra instr. handled per proc.**
Experiment 1: Single surgeon, preferences and schedule per Table 1									
\$50	\$10	\$29,113	\$28,020	3.8%	\$37,406	6	14	1.05	0.2
\$100	\$10	\$29,763	\$28,720	3.5%	\$37,406	6	14	1.05	0.2
\$500	\$10	\$34,963	\$34,320	1.8%	\$37,406	6	14	1.05	0.2
\$50	\$100	\$54,043	\$53,082	1.8%	\$38,565	6	14	1.03	0.1
\$100	\$100	\$54,693	\$53,782	1.7%	\$38,565	6	14	1.03	0.1
\$500	\$100	\$59,893	\$59,099	1.3%	\$40,612	5	13	1	0.9
Experiment 2: Two surgeons, non-overlapping schedules									
\$50	\$10	\$59,650	\$46,744	21.6%	\$49,744	9	28	1.20	1.03
\$100	\$10	\$60,300	\$48,144	20.2%	\$49,744	9	28	1.20	1.03
\$500	\$10	\$65,500	\$59,100	9.8%	\$51,791	8	26	1.17	1.42
\$50	\$100	\$109,510	\$98,805	9.8%	\$73,344	11	28	1	0.56
\$100	\$100	\$110,160	\$100,200	9.0%	\$73,344	11	28	1	0.56
\$500	\$100	\$115,360	\$110,920	3.8%	\$51,791	7	23	1.01	8.43
Experiment 3: Two surgeons, overlapping schedules									
\$50	\$10	\$67,903	\$50,233	26.0%	\$57,608	11	31	1.31	0.60
\$100	\$10	\$68,203	\$51,698	24.2%	\$59,378	10	29	1.20	1.0
\$500	\$10	\$73,403	\$63,221	13.9%	\$62,851	10	28	1.16	0.84
\$50	\$100	\$120,373	\$102,990	14.4%	\$73,344	11	28	1	0.56
\$100	\$100	\$120,673	\$104,390	13.5%	\$73,344	11	28	1	0.56
\$500	\$100	\$125,873	\$115,200	8.5%	\$70,405	10	27	1.01	0.71

Depending on the tray-cost parameters, the annual savings range between \$10,000 and \$13,500 in the case of non-overlapping schedules for the two surgeons, and \$10,100 and \$17,700 when the schedules of the two surgeons overlap. This contrasts with the annual savings of \$600 to \$1,100 when we considered tray optimization for a single surgeon. This suggests that savings from optimization grow significantly with an increase in the number of surgeons.

Comparing the results of Experiments 2 and 3 shows that physician schedules influence costs, and for different schedules, different tray configurations can be preferable. But in all cases, the majority of savings is due to handling fewer instruments. A sample case is highlighted in Table 2. In the optimized benchmark configuration with only four tray types, on average, 24.7 extra instruments are handled per procedure; here, in the optimized configuration with nine tray types, only 1.03 extra instruments are handled. The annual savings on washing alone is 540*(24.7-1.03)*$1.05 =$13,381. The additional savings of $1,755 is from reduced handling, wear and tear, because fewer instruments are used.

Another observation is that the tray holding and usage costs *implied* by the current configuration appear to be rather large. We observe that the smallest percentage difference in annual costs between the current and an optimal configuration occurs when the annual cost of holding a single tray is $500 and the cost associated with opening a tray during a procedure is $100. We question whether these estimates are reasonable. One benefit of a decision support system for determining the composition of trays is that the use of such system transforms the debate from *opinions* that one composition is preferable to another to a question of what reasonable estimates are for holding and usage costs of a tray.

5. Discussion and Conclusion

As hospitals look at cost-saving initiatives, one area that they may explore is rationalizing surgical instrument trays for the operating rooms. To examine the impact of optimization, we obtained instrument preference data and past surgical schedule data from general surgeons in a midsize U.S. hospital. A variety of costs are involved in owning, maintaining, and using reusable surgical instrument trays; some of the costs could be difficult to quantify. We conducted numerical experiments for a range of reasonable cost parameters. Our numerical experiments suggest that, with tray optimization, surgical-instrument-related costs can be reduced significantly without a noticeable increase in the number of trays in inventory, the average number of trays opened during a procedure, or the number of instruments handled. We also observed that, as the number of surgeons operating in a facility increases, the potential for savings also increases because there are both shared instruments among surgeons and specialized instruments for each surgeon.

Based on our observations and discussions in one hospital, we suspect that materials managers underestimate the cost of reprocessing extra instruments and overestimate the holding costs of inventory. This bias leads to a smaller variety of trays with more instruments and therefore larger costs, due to reprocessing of extra instruments. Some hospitals consider other solutions (bar codes, RFIDs) for identifying instruments and placing them into correct trays, but costs and implementation difficulties mean that these innovative methodologies have not yet been widely adopted (Ochiai, 2009). Introduction of such technologies would reduce per-procedure costs associated with instruments and trays. Certainly, a more careful analysis needs to be performed. Introduction of such technologies could simplify sorting instruments into trays and reduce errors related in missing instruments; it would also increase instrument acquisition costs. The methodology introduced here could be useful in evaluating such technological acquisition because the low-cost tray configuration may change once such a technology is adopted.

Some of the savings predicted by our model may not result in actual cost savings, because the facility still needs to employ staff for a certain number of hours. But the time saved in reprocessing instruments can be spent managing a larger variety of trays, which will result in higher satisfaction for surgeons.

Hospitals may want to explore other ways to reduce costs, such as standardization of procedures. The methodology presented in this paper can help prospectively quantify the potential payoff from the standardization effort. Likewise, as the set of surgeons with privileges at a hospital changes over time, our methodology could predict the value of changing the configuration of the trays.

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