Instrument trays revised

A research into the benefits of alternative trays compositions for the surgery department in the Medisch Spectrum Twente

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Abstract

Instrument trays hold sets of instruments used during surgery. Some trays are specifically matched to particular procedures. However, most trays hold large instrument sets that are used by a wide range of procedures. Regardless of the number of instruments available from the tray that are actually used during surgery, the complete content of the tray has to be (re-)sterilized afterwards. By more closely matching the content of instrument trays to the procedures they are used for, sterilization costs might be reduced drastically. In this research we define a methodology for minimizing the number of sterilizations per year. We therefore change the composition of some frequently used instrument trays. This research is performed in the Medical Spectrum Twente and focusses on 11 surgical procedures of the surgery department. We reallocate the instruments currently used for these procedures by using an LP model. We estimate the savings that can be realized when reallocating instruments for a particular set of procedures. We expect the costs can be reduced by at least €50,000.

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1 Introduction

Hospitals deal with a large number of instruments used for clinical procedures. The characteristics of these instruments can be dimensioned by, for example, their function, substitutability, or complementary properties. Furthermore, some instruments come in the form of disposables while others are reused after being cleaned and sterilized. The latter type of costly instruments are primarily used in the operation theatre of the hospital and entail a couple of unique properties:

1. The instruments are stored in metal baskets called *instrument trays* that form a complementary instrument set. The trays are folded in a special airtight paper that keeps the instruments sterile after the sterilization process.

2. Since the instruments are reused, the complete content of an instrument tray needs to be cleaned and sterilized after being opened.

3. Cleaning and sterilization is done at a remote department, the *Central Sterilisation department* (CSD), which operates under strict hygienic regulations that directly affect the lead time of the sterilization process.

4. The quality of instruments needs to be monitored and instruments need to be replaced when worn out.

By placing instruments together in an instrument tray, tray compositions can be defined that match the instrument-needs during surgery. Furthermore, by combining instruments in trays, the operating room assistants can more easily collect all the instruments that are needed. Depending on the complexity of the surgical procedure, one or more instrument trays might be used. However, when a single instrument tray is opened, regardless of the actual number of instruments from the tray used, the complete set of instruments needs to be cleaned and sterilized afterwards.

The activities in de CSD are very labor intensive and involve investments in expensive (cleaning and sterilization) equipment, which makes the sterilization process very costly. From this point of view, hospitals will try to minimize the number of instruments that need sterilization after surgery. Properties (1) and (2) then give raise to the question how to best match the content of the instrument trays to the medical procedures as to minimize the number of unused instruments that need sterilization after surgery.

Keeping additional instruments (or instrument trays) in inventory invokes high material investment and holding costs. Therefore, the collection of instrument sets kept in inventory should be minimal. However, the (un)availability of materials should not form a bottleneck for surgical planning.

The main problem then is how hospitals can minimize sterilization and material handling costs by altering the composition of instrument trays. The goal of this research is to find a consistent methodology to minimize the number of instruments per instrument tray while guaranteeing instrument availability. This research is performed in the *Medical Spectrum Twente* (MST) and focuses on the instruments used by the surgery department. The MST is a facilitator of health care services in the region of Twente, the Netherlands. Its top clinical hospital is located in Enschede. Most surgical procedures are performed in Enschede, which holds 17 operating rooms. Four operating rooms are exclusively allocated to the thorax centre located in another department. Oldenzaal holds 4 additional ORs. Common procedures are mainly performed in Oldenzaal. Both Enschede and Oldenzaal have their own CSD, however Enschede's CSD is considerably larger. The CSD is located next to the operating rooms. The CSD in Enschede has a total of 26 customers (including external parties) and approximately 80% of its throughput is initiated by the operating rooms.

In this research, we study the composition of instrument trays used by the Surgery department of the Medical Spectrum Twente. Our main research question is:

How can the composition of instrument trays in the Medical Spectrum Twente be optimized?

The main research question is supported by the following sub-questions:

1. How many instrument trays are currently used?
2. What are the most frequent surgical procedures and how can these procedures be characterized concerning instrument usage?
3. How can the instrument trays be matched to these procedures?
4. What are the benefits of rearranging particular trays?

We thus select some frequently performed surgical procedures for which the number and type of instruments used is relatively predictable. For these procedures it might be beneficial to design unique instrument trays. In the next section, we explain our methodology in more detail.

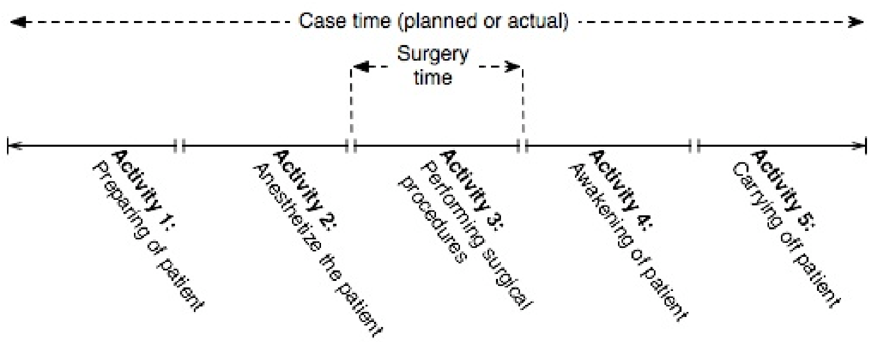

Figure 2.1: Operations consists of subsequent activities. Furthermore, the surgery time consists of the time needed to perform one or more surgical procedures.

2 Methods

2.1 Definitions

We distinguish *tray-types* and *trays*, since a tray-type can be represented by one or more trays. For example: the "basic" instrument tray-type[1] has a multiplicity of 37 and the "abdominal tray for children" has a multiplicity of 1. In the MST, tray-types are distinguished with a unique ID according to the formatting (*user*)-(*number*). In our example, the basic tray has ID *AC-001*, being the first tray-type of general surgery (or *Algemene Chirurgie* in Dutch).

We distinguish *operations* and *procedures*. An operation consists of subsequent activities (see Figure 2.1 for an illustration): (1) preparing of the patient in the OR, (2) anesthetize the patient, (3) performing surgical procedure(s), (4) awakening of the patient, and (5) carrying of the patient. One operation can include one or more surgical procedures: for example, the surgeon might have decided to do more than one treatment during an operation, resulting in more than one procedure being performed. Surgery time consist of the time needed for all surgical procedures. In this context, a surgical procedure can thus be interpreted as a stand-alone treatment which can be combined with other surgical procedures during a single operation. We distinguish procedures by their unique CTG-code[2].

The ORs are scheduled on the expected time needed for an operation[3], hence activities (1) to (5). We refer to this total time frame as the *planned case time*. During the operation, the actual times needed for the subsequent activities (1)

[1]The "basic" instrument tray holds instruments that are used for almost every surgical procedure.

[2]The surgeon registers all performed procedures (CTG-codes) after finishing surgery. The CTG-codes are used for the financial administration of operations. Nowadays, CTG-codes are replaced by *Activity-codes*, however, they are closely related and can be interchanged easily.

to (5) are registered. The actual time frame needed to perform an operation is referred to as the *actual case time*. The actual case time includes the surgery time. The surgery time is used in our analysis, which will be explained later on.

2.2 Research Design

We aim to reduce unnecessary sterilizations by more closely matching the tray composition to the instrument need during surgery. The largest benefits can be obtained when focussing on the most frequently performed surgical procedures. The trays currently used for these procedures initiate the majority of sterilizations at the CSD. However, the tray compositions can only be matched to procedures that use standard sets of instruments. For these procedures, alternative tray compositions might drastically reduce the number of redundant instrument sterilizations. We thus analyze (1) the collection of most frequently sterilized trays and (2) the procedures that initiate this production. Regarding these procedures, we focus on those that use a standard set of instruments. Consequently, we need a measure for predicting the stability of instrument use for a particular procedure.

In Section 3.1 we present the production statistics of the CSD, i.e. the number of trays that are cleaned, packed, and sterilized on a yearly base. The production analysis focuses on the CSD-production in Enschede from May 2005 to May 2008. This results in an overview of trays that are sterilized most often.

In Section 3.2 we present the procedures that use a standard set of instruments and that initiate the mass of CSD production. We expect that procedures that use a standard set of instruments tend to be predictable in performance and outcome: the surgeon is familiar with the disease, treatment and outcome of surgery, i.e. the qualitative measures. We furthermore expect these procedures are frequently performed and have relatively short surgery times, the quantitative measures. This makes *surgery time* and *frequency* useful indicators for the stability of instrument use. This (expected) relation is illustrated in Figure 2.2. We will verify this relation later on. Regarding our selection of relevant procedures, we also account for procedures that might be related to each other. Since more than one procedure might be performed during surgery, some procedures might have a high relative risk of "triggering" others. If certain procedures are frequently performed alongside others, this might drastically alter the instrument needs. We evaluate this risk by determining the *relative risks* of combinations of procedures.

We use the expert knowledge of the OR-assistants to define the exact set of instruments needed for the final selection of procedures. In Section 3.3 we present a method for allocating the instruments to the trays.

Although we have no cost price information regarding the sterilization per unit, we give an indication of the cost benefits that can be obtained. The CSD

[3] The hospital uses computer software to automatically plan the time frames for operations. It automatically determines the expected case time based on historical data, but it is unclear how this time is calculated. The expected time as presented here should thus not be interpreted too literally, i.e. as an estimated statistical expectation.

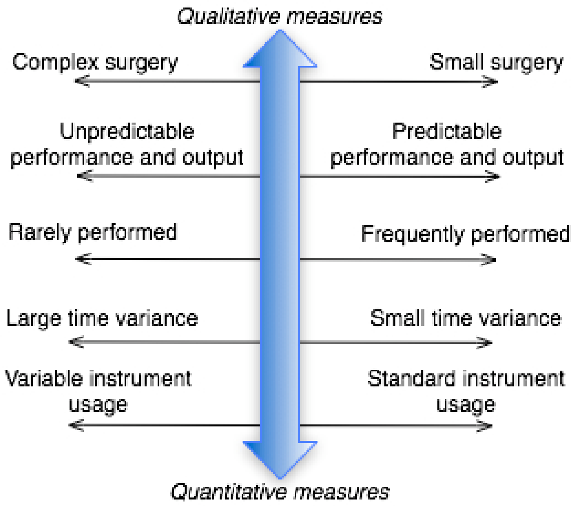

Figure 2.2: We expect that the complexity of surgery (indicated by qualitative measures) can, on average, also be indicated by quantitative measures. The quantitive measures *frequency* and *surgery time* might then indicate the variability in instrument use.

is budgeted on a yearly basis and the relation to actual production costs appears to be unclear.

Figure 2.3 shows an overview of the research design.

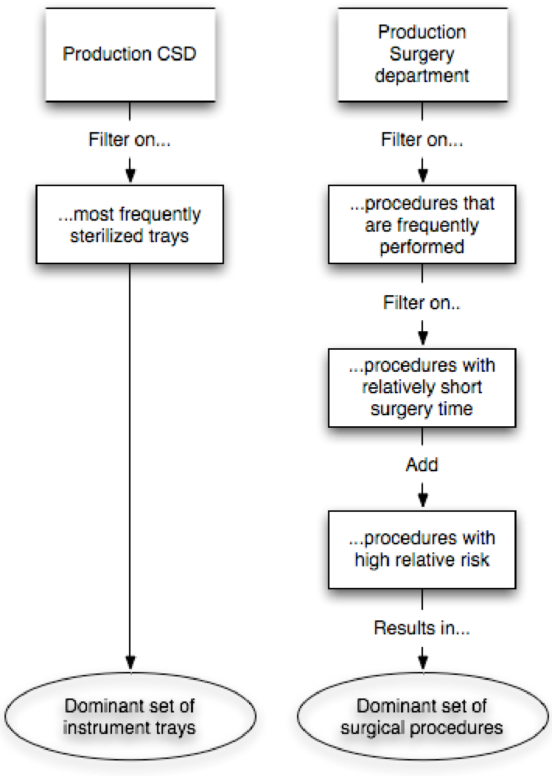

Figure 2.3: The research design as described in this section

3 Results

This section presents an overview of the number and type of instrument trays that are used. We analyze the number of trays that are sterilized and the number of surgical procedures performed. This indicates the relation between certain procedures and frequently used trays.

3.1 Instruments and instrument trays used

The production statistics of the CSD indicate that approximately 565 tray-types passed the CSD per year during the past 3 years (2005-2008), corresponding to 1710 trays per year. By approximation, the majority of demand was initiated by the ORs: 500 tray-types (1300 trays). The outpatient department accounted for 20 tray-types (250 trays) and the thorax centre for 45 tray-types (160 trays). The ORs thus account for approximately 80% of the demand at the CSD. These statistics indicate the minimum inventory of tray-types available. Because of the limitations of the information system used, we have no clear indication of the actual number of tray-types in inventory (some tray-types might have remained unused over the past 3 years and thus do not show up in the CSD's production statistics).

All trays used by the ORs are stored in cabinets located between the CSD and the ORs. The OR assistants withdraw trays one day in advance of the OR schedule. During the day, used trays that need sterilization arrive at the CSD in batches, since they are transported in trolleys at select intervals. After sterilization, the cabinets are replenished by the CSD. Table 3.1 shows an overview of all trays that are related to the surgery department. Oncologic surgery has no unique trays, contrary to trauma and vascular surgery. The general surgery trays (having ID: $AC - ...$) are also used by other specialisms since they contain a lot of common instruments.

Figure 3.1 indicates the cumulative distribution of trays over production and inventory. The tray-types depicted correspond to the same trays as shown in Table 3.1. We conclude from Figure 3.1 that a small group of tray-types account for the largest production at the CSD. Furthermore, this same collection of tray-types accounts for the largest part of inventory.

Alternative tray compositions are most beneficial for the collection of trays located at the far left of the horizontal axes of Figure 3.1, since these trays are used most frequently. We therefore focus on the first 20 tray-types. Table 3.2 shows an overview of these 20 tray-types. We expect that there are some frequently performed surgical procedures that use one or more of these trays.

3.2 Surgical procedures performed

From 2006 to 2008, the surgery department performed approximately 11,000 operations, corresponding to 360 different CTGs. In this section, we analyze the frequency of these surgical procedures and relate this to instrument use.

Table 3.1: The number of tray types and the total number of trays used by the surgery department in the OR during the past 3 years. Oncologic surgery has no unique instruments.

Specialism	Number of tray types	Total number of trays
Surgery (general)	27	141
Oncologic surgery	-	-
Trauma surgery	88	140
Vascular surgery	25	54
Total	140	335

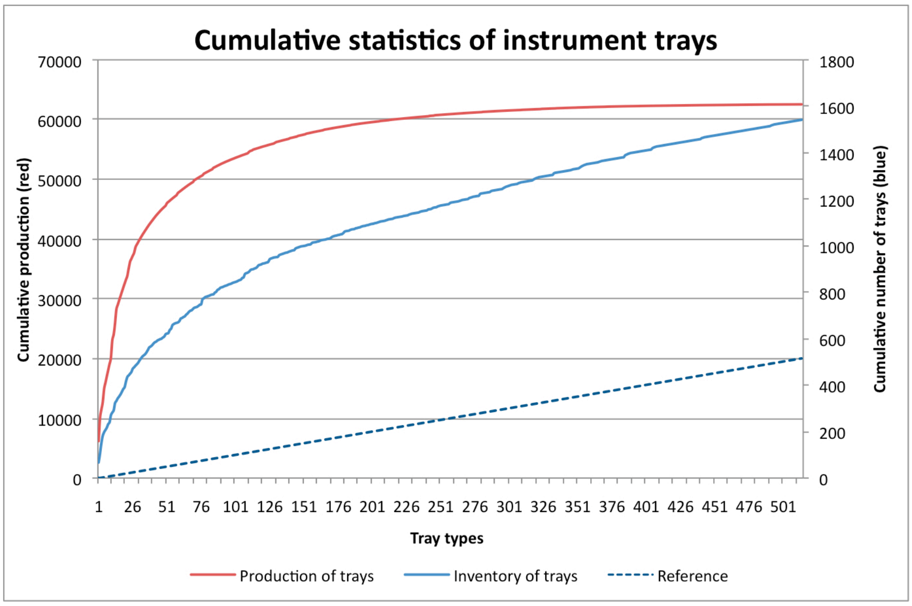

Figure 3.1: This graph indicates the cumulative production and inventory of trays. A small portion of tray-types (located on the far left of the horizontal axis) accounts for the largest production of trays. These trays also correspond to the largest part of inventory. The "reference" line indicates the slope of the graph for tray-types that are represented by 1 tray (slope of 1)

Table 3.2: The collection of trays selected based on the production of the CSD. Some tray-types assigned to general surgery are also used by other specialties. This especially counts for tray-types AC-001, AC-002, AC-003 and AC-022.

Tray ID	Description	Prod. 07-08	# Trays
AC-001	basisset alg	3858	37
AC-003	kindernet alg	1092	16
AC-002	abdominaal alg	1046	15
AC-022	laparoscopisch net alg	782	10
TRAUMA-035	klein bottennet alg	550	7
VAAT-058	fijn vaatnet vaat	502	6
AC-059	0 graden optiek 10mm doorsnee panoview	329	11
AC-012	klein instrument alg	302	5
TRAUMA-034	groot botten net alg	297	6
AC-007	anaal net alg	266	5
VAAT-048	grays blades omnitract	241	2
TRAUMA-112	small fragment	209	3
AC-009	ultracision alg	179	5
TRAUMA-043	cerclage net + k-draden	178	3
VAAT-055	groot vaatnet vaat	149	6
TRAUMA-036	repositietangen alg	135	5
VAAT-030	bloedleegte set boazul vaat	119	7
TRAUMA-037	hip fracture sys alg	107	2
AC-018	thorax alg	92	3
TRAUMA-130	omega 2 dhs onder-+bovenblad	88	2

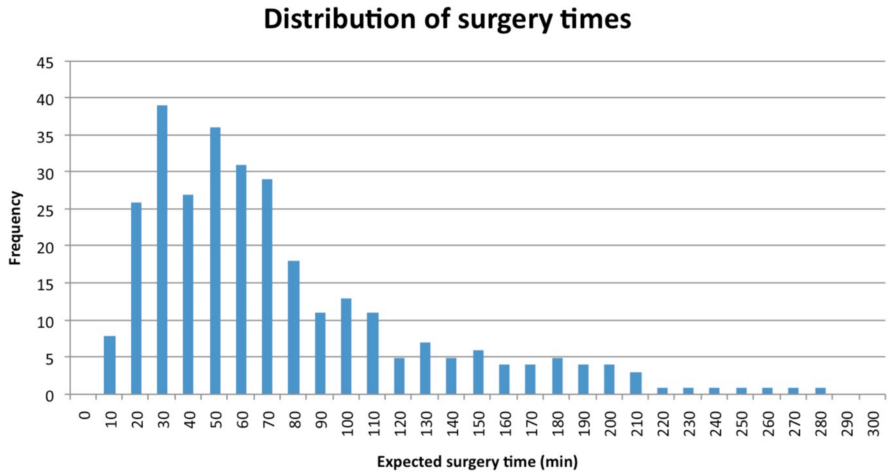

Figure 3.2: Most surgery times take between 20 and 30 minutes. Long surgery times have a small frequency of occurrence.

Although most operations include only a single procedure, we do have to take into account that particular procedures might be performed simultaneously.

In Section 1 we introduced a dimensioning of procedures. We now verify this relation between the frequency of procedures and their expected surgery time. We expect that frequently performed procedures will have relatively short surgery times. Figure 3.2 shows a frequency diagram of the expected surgery times. This shows that relatively short surgeries (i.e., between 20 and 70 minutes) are most frequent.

When selecting the most frequently performed procedures, we might thus select the most predictable ones concerning instrument use. Table 3.3 shows an overview of all 11 procedures selected. This selection is based on all procedures that:

1. ...are performed 200 times or more per year,
2. have a relatively short expected surgery time; between 20 to 70 minutes
3. do not need all instruments available from the trays that are used.

According to the expert knowledge of the OR-assistants, the selected procedures indeed use small, standard sets of instruments. The trays currently used for these procedures can be recognized from Table 3.2 and consequently account for a large part of CSD production. Furthermore, we determined the relative risk of these procedures initiating others. This does not result in additional procedures that have to be taken into account. In other words, the statistics indicate that the procedures depicted in Table 3.3 are not frequently performed together with other procedures during operations. In the next section, we will optimize the tray composition for this selection of trays.

3.3 Alternative tray compositions

We define a methodology for determining near optimal tray compositions for the 11 surgical procedures presented in the previous section. At the moment, large and commonly used tray-types are used for these short surgeries. Altering the tray composition for these specific procedures might drastically reduce costs.

The goal is to minimize the number of instrument sterilizations per year. We have a number of instruments that have to be allocated to a select number of trays. This results in a finite number of allocations that have to be evaluated. The best allocation is the one that results in the smallest CSD production costs. This problem is characterized as a discrete optimization problem which can be formulated in an LP model:

Sets

- The set of instruments I that have to be allocated to trays (index $i = 0...|N|-1$).
- The set of trays T that have to be filled (index $t = 0...|T|-1$).
- The set of surgery IDs (or CTGs) S that correspond to the selection of 11 procedures (index $s = CTG_1...CTG_{11}$).

Parameters

- Parameter n_s indicates the number of times surgery s is performed per year.
- M ("bigM" parameter) equals the maximum value that $X_{i,t}$ can attain.
- Parameter a is the maximum number of items we allow to be placed in a single tray.
- $b_{i,s}$ gives the minimum number of instruments of type i that should be available to perform surgery s. In other words, this parameter indicates the instrument needs during surgery as indicated by the OR assistants.

Variables

- Variable $X_{i,t}$ as the number of instruments of type i allocated to tray t.
- Variable $Y_{t,s}$ as a binary variable indicating whether tray t should be used by surgery s.
- Variable $Z_{i,t,s}$ as an auxilary variable indicating the number of items i of tray t available for surgery s Consequently, $Z_{i,t,s}$ equals the product of $X_{i,t}$ and $Y_{t,s}$.

Objective

- Minimize the total number of instruments sterilized per year.

Constraints

- A combination of constraint defining the relation $Z_{i,t,s} = X_{i,t}Y_{t,s}$ in linear form.

Table 3.3: Overview of all trays selected based on our data analysis including the tray-types used per procedure.

CTG	Description (Dutch)	Freq.	Exp. surg. time (95% CI)	Tray- types used
35700	Hernia inguinalis / lichtenstein plastiek / BZR / liesbreuk	687	45.39 - 47.71	AC-001
33656	Crossectomie	526	50.9 - 54.12	AC-001
35138	Haemorrhoidectomie	439	16.96 - 18.52	AC-007
33780	Diagnostische lymfeklierextiraptie supr / infra claviculair	372	37.38 - 45.12	AC-003
34910	Appendectomie	344	35.88 - 39.55	AC-001
35512	Buik spoelen	339	38.37 - 44.69	AC-001, AC-002
38912	Excisie fibro-adenoom	431	22.32 - 24.86	AC-001
33911	Excisie biopsie mamma + localisatie	381	32.34 - 35.57	AC-001
38853	Peri-anaal abces	538	13.72 - 15.63	AC-007
34738	Colonresectie	336	84.2 - 90.77	AC-001, AC-002
35350	Cholecystectomie / galblaas	295	58.53 - 64.96	AC-001, AC-002

- The number of instruments of type i that are available during surgery s should be larger than or equal to $b_{i,s}$.
- The number of instruments that can be allocated to a single tray should be smaller than or equal to a. By doing so, we prevent trays from becoming to large or heavy.

Then the mathematical LP model formulation is:

$$\text{minimize} \quad \sum_s (n_s \sum_{i,t} Z_{i,t,s}) \tag{1}$$

$$\begin{aligned}
\text{s.t.} \quad Z_{i,t,s} &\leq M \cdot Y_{t,s} && \forall i,t,s && (2)\\
Z_{i,t,s} &\geq X_{i,t} + M \cdot (Y_{t,s} - 1) && \forall i,t,s && (3)\\
X_{i,t} &\geq Z_{i,t,s} && \forall i,t,s && (4)\\
\sum_t Z_{i,t,s} &\geq b_{i,s} && \forall i,s && (5)\\
\sum_i X_{i,t} &\leq a && \forall t && (6)\\
& X_{i,t}, Z_{i,t,s} \in \mathbb{Z}^+ && && (7)\\
& Y_{t,s} \in \mathbb{B} && && (8)
\end{aligned}$$

Then (1) defines the goal function which minimizes the total number of instruments sterilized on a yearly basis. Constraint (2) to (4) define the relation $Z_{i,t,s} = X_{i,t} Y_{t,s}$ in a linear format. Constraint (5) guarantees that the minimum number of instruments of type i are available for surgery s and (6) Indicates the maximum number of instruments that we allow to be allocated to each tray.

We run the LP model in CPLEX and evaluate different scenario's. We solve the model using 115 different types of instruments (i = 1...115) and 11 procedures ($s = CTG_1..CTG_{11}$). We vary the number of trays from 6 to 9 (t = 1...6/7/8/9). This gives an indication of the cost reduction possible when allowing more trays to be used for covering the instrument needs for all 11 procedures. Furthermore, we evaluate the effect of limiting the maximum number of trays that can be allocated to surgeries. This prevents the model from suggesting solutions that demand too many trays per surgery. The following additional constraint is then added to the model:

$$\textstyle\sum_t Y_{t,s} \leq \quad B \tag{9}$$

...where the parameter B indicates the maximum number of trays per surgery allowed. We assume the costs per instrument sterilization are approximately €1 per instrument. This estimation is based on information from other hospitals in the Netherlands. Although we are unable to determine the precise cost benefits that can be obtained in the MST, our solutions does indicate the reduction in CSD production possible (number of instruments) and the fraction of cost savings possible (percentage).

After solving the model, some solutions might suggest particular instruments to be placed in more than one tray. We do not put a constraint on the availability of instruments. Since the instruments that are allocated are currently located in tray-types that are widely available, we assume the instruments are also widely available. Moreover, the instruments that are reallocated are characterized as standard instrument sets and we expect additional instruments are hold in inventory as spares.

Because of the large size of the solution space (the problem is NP-hard), we interrupt the solver after 1800 seconds. Let the current costs be defined by $\sum_s(N_s \sum_{i,t} \tilde{Z}_{i,t,s})$. Here, $\tilde{Z}_{i,t,s}$ is the number of instruments of type i from tray t available during surgery s available in the current situation. These costs currently sum up to €332,334. The savings are calculated by substracting the objective result from the current yearly costs. We varied the values of constraint (6) to give an indication of the effect on the objective results. The best integer solutions and integrality gap obtained after a 1800 second run are shown in Table 3.4.

Most savings are in the range of €55,000 to €65,000. Since we interrupted the solver, we cannot compare the results and conclude with a final ranking of solutions. However, Table 3.4 does indicate that savings of at least €55,000 are possible. In theory, the highest savings can be obtained if the number of available trays, T, equals the number instruments that have to be allocated, n. This would result in $T = 115$. In practice, this means that instruments are packed per single unit. This completely prevents redundant sterilizations: only instruments that are used during surgery are sterilized afterwards. Although this configuration is far from preferable (it invokes high material handling costs since all instruments have to be collected single-handedly), it can be referred to as a lower bound on all possible solutions. Then the (integer) lower bound is defined by $\sum_s(N_s \sum_i I_{i,s})$ which equals €235,282. As a result, the maximal savings possible are €97,052.

Table 3.4: The table shows the solutions obtained for a 1800 second run of the ILP model in CPLEX (savings are indicated in €/year)

Solution	T	A	B	Best integer sol. value	Integrality gap (%)	Savings (€)
1	8	60	3	268,372	17	63,724
2	9	60	3	277,544	18	54,552
3	7	60	3	271,947	15	60,149
4	8	-	-	266,480	13	65,616
5	8	60	-	274,021	16	58,075
6	7	70	3	280,371	19	51,725
7	6	50	3	298,961	17	33,135
					Current costs	332,096

4 Conclusion and discussion

In this research, we studied the production of the CSD and the procedures performed by the surgery department. The goal was to find a methodology to minimize (redundant) sterilizations of instrument trays. We focussed our research on 11 frequently performed procedures that initiate the majority of demand at the CSD. We optimized the tray composition for these procedures. Using an LP model we were able to give an estimate of savings possible. Optimal solutions could not be determined, since our problem is NP-hard. We conclude from the solutions of our LP model that savings of at least €50,000 are possible.

We used the expert knowledge of the OR assistants to determine the instruments that are needed per procedure. However, these indications slightly differ per person. The actual instrument use per procedure has to be verified during surgery before implementing new tray compositions. After implementation, this guarantees that no instruments will be missing during operations.

We have no cost price information available to indicate the sterilization costs per unit. We used an average €1 per unit based on information from other hospitals in the Netherlands. Reliable cost price information for the MST will give a better indication of savings that can be obtained.

Our solution might require additional investments in instruments. We assumed that the availability of instruments does not form a constraint on the new tray compositions. The instruments we reallocated are currently allocated to trays that are widely available in inventory. We therefore do not expect the availability of instruments to become a serious bottleneck. Furthermore, additional investments in some instruments does not outweigh the savings possible for alternative tray compositions.

Our savings are based on the assumption that the alternative trays are available for surgery when needed. In reality, this however might not always be the case. Since more common trays are widely available, the availability of instruments will be guaranteed. As a result, the unavailability of the optimized trays will not create a bottleneck for operations scheduling.

The current LP model is NP-hard. Therefore, an optimal solution cannot be easily determined in polynomial time. Improvements to our current solutions might be obtained by using improvement heuristics. For example, using simulated annealing might result in even better solutions. For evaluating improvement heuristics or other ILP formulations, further research is needed.