Medical Instrument Tray Optimization

Combining Use Rates, Expert Opinions and Risk Analyses

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LUMC

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By

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T. van Trier
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Medical Instrument Tray Optimization: Combining Use Rates, Expert Opinions and Risk Analyses

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December 2, 2019

1 Abstract

Background: The operating room (OR) and central sterile supply department (CSSD) are two resource-intensive healthcare departments. Reducing the environmental and financial impact of these departments is of great importance in the global debate on sustainability. Removing unnecessary items from instrument trays may provide a partial solution. However, improvements to tray compositions are often time-consuming, not permanent and not using the full reduction potential. As the Leiden University Medical Center (LUMC) is considering adopting radio-frequency identification (RFID) techniques to register instrument use automatically, it is important to know how tray composition can be optimized with this data.
Goal: This research compares different methods of medical instrument tray optimization and combines different aspects to create a new methodology.
Methods: Three models compared and evaluated objective and subjective instrument use percentages and different suggestions for tray optimizations. New tray compositions, based on objective use rates, were discussed with the medical specialists and attuned to their requirements. The result was then reviewed by the OR-assistants, before making any final adjustments. This methodology is tested for abdominal instrument trays at the gynecology department of the Leiden University Medical Center (LUMC). The new trays were evaluated over a test period and missing items were registered during follow-up. Risks to patient safety as a result of missing individual instruments and chances of missing instruments for different reduction methods are discussed and quantified.
Results: Mean use rates of the designated instrument sets are 28.4% (SD=6.43%) for open surgery (n=16) and 47.6% (SD=8.16%) for minimally invasive procedures (n=12). A 37% reduction of instruments is reached across three abdominal trays by removing unnecessary items. Weight of the contents of the trays is reduced by 31%. During the evaluation (n=7 procedures), mean instrument use for abdominal procedures increased from 28.4% (SD=6.43%) to 46.47% (SD=10.96%) after tray optimization. A reduction based on use rates with a 10% cut-off or based on the recommendations of the medical specialists, induces an 8.7% or 3.9% chance of missing any instrument during the procedure, respectively. Tray content reductions based on OR-assistant suggestions and objective use rates with a 0% cut-off are safe, but do not utilize the complete reduction potential.
Conclusions: Different tray optimization methods were compared. Use rates were measured in the OR and expert recommendations were discussed in group sessions. A combination of objective use rates and subjective expert considerations can lead to a significant reduction of the amount of unnecessary items in the medical instrument cycle without harming patient safety. Group consensus amongst medical specialists suggests the most radical reduction of instruments on the tray, but increases chances of missing instruments during surgery. Recommendations based on use rates have to be supplemented by reduction efforts based on the clustering of equivalent instruments.
Recommendations: Future work should focus on ways to scale reduction efforts to an autonomous hospital-wide system and teach optimization models to mimic human expert input. It should also focus on exact measurements in the CSSD to estimate reductions in costs and CO2-footprint reliably.

Contents

2 Introduction

Health care costs continue to rise, putting health care systems around the world under immense pressure. The Dutch health care system passed the 100 billion euros mark last year, spending roughly 28% on specialist medical care in hospitals [23]. A global call for sustainability complicates matters even further, pressurizing patient safety standards by enforcing circularity, resource-sparing behavior and green initiatives. Removal of non-value adding process steps, according to Lean methodology, has proven to reduce costs and improve sustainability in a wide range of industries [8, 12]. For health care purposes, this methodology has been shown to increase operating room (OR) and central sterile supply department (CSSD) efficiencies [5, 20]. Processes in the OR and CSSD are linked by the flow of reusable medical instruments in the medical instrument cycle, as shown in Fig. 1. The use phase takes place in the OR, whereas the cleaning, disinfection, inspection, packaging and sterilization of instruments take place in the CSSD. Based on the specific hospital lay-out and the type of instrument, storage can take place either in the OR or the CSSD. Clearly, reducing the number of instruments in the cycle affects many different processes.

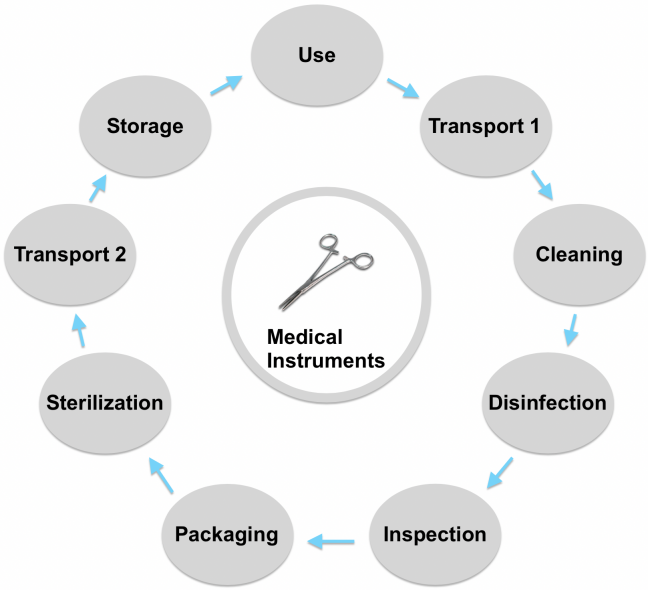

Figure 1: Processing of Reusable Medical Instruments

Research by Stockert et al. (2014) and van Meter et al. (2016) indicates use rates of medical instruments between 13.0% and 21.9% across different specialized instrument sets [18, 19]. Reducing some of the excess instruments on the trays will significantly improve efficiency, reduce costs and promote sustainability around the OR [1, 9, 21]. Other described benefits include reduced tray weight, increased personnel satisfaction, decreased processing and preparation times, reduced OR waste and reduced water, electricity and chemical use [2, 6, 7, 13]. Naturally, patient safety is still the main concern in any optimization effort. Reducing redundant instruments may not impose extra hazards on patients and personnel [18]. However, in turn, time spent counting excess instrumentation may also decrease patient safety and increase procedure times [4]. In general, it has been shown that standardization and reduction of surgical equipment can lead to the desired advantages without harming patient safety or quality of care [9, 11].

Whereas other relevant literature describes reduction efforts solely based on use rates [3] or group-consensus models [10], the current research chooses to supplement those methodologies with an integrated risk analysis, further minimizing patient safety hazards. In case of a data-based approach, one has to choose a cut-off use percentage. The hospital can choose to remove the instruments that are never used, but might consider to remove rarely used items as well. Chin et

al. describe a cut-off percentage of 20%, but do not provide any insight as to why this would be the appropriate percentage [3]. Lastly, it tries to determine whether a subjective or an objective approach is best to reduce unnecessary items from rotation.

This article proposes a new method to optimize the contents of medical instrument trays in secondary and tertiary healthcare institutions, based on objective use rates, subjective opinions by specialists and OR-assistants and thorough risk analyses. As traceability of instruments is becoming more important and as the LUMC is considering adopting radio-frequency identification (RFID) techniques to register instrument use automatically, it is important to know how tray composition can be optimized with this data. The risk analyses are also essential, as the instrument trays are used in a highly complex environment with multiple stakeholders. The OR-assistants, the medical specialists and patient safety are all directly concerned with any changes to the instrument trays. Indirectly, changes in composition also influence CSSD personnel and management. This research tries to find an optimal method for tray optimization, describes a way to calculate the appropriate cut-off percentage for a data-based approach and it hypothesizes that there is a gap between subjective (asking the medical specialist) and objective (measuring in the operating room (OR)) instrument use rates. Also, it hypothesizes that a combination of use rates, specialist input and risk analyses, can lead to a significant reduction in the contents of the trays, without jeopardizing patient safety. The methodology is evaluated in a pilot study at the gynaecology department of the Leiden University Medical Center (LUMC).

3 Methods

3.1 Study Design

This research is an observational study, performed at the Leiden University Medical Center (LUMC).

3.2 Data Collection

The actual objective instrument use rates were determined by counting instrument use in the OR for four different medical instrument trays in the gynecology department. Three trays were used during oncological laparotomies, whereas the fourth was used for minimally invasive surgery. An instrument was defined as 'used' when it was held by the medical specialist. The data was corrected for non-simultaneous use. Therefore, the use of three pairs of tweezers over the complete procedure was counted as two pairs, in case the third pair was not used simultaneously to the other two. Also, directly alternating use of two pairs of instruments, for example needle drivers, was counted as two separate uses. Lastly, these rules do not include instruments that are removed from the sterile field during the procedure. The OR-assistant may not always hand the same pair of tweezers to the specialist. Therefore, the data was organised per instrument type.

The subjective instrument use was determined by asking the medical specialists and OR assistants to estimate the use frequency on a scale of 0 - 3 (where 0 is never, 1 is sometimes, 2 is often and 3 is always) on a questionnaire. Also, they were given a list of the current tray contents, and asked to suggest a minimal, desirable number on the tray for every specific instrument. The same questionnaire was used to acquire the data for the risk analysis, as described below. This subjective data was compared to the objective data to identify differences. Furthermore, this data, combined with a risk analysis, was used to see if objective data suffices to optimize tray compositions. As the medical specialists were having trouble to identify the instruments solely based on the official name and a small picture, it was decided to redo this step and acquire the data by doing group sessions. At least three gynecologists had to be present for the evaluation of every tray. Being able to actually hold the instrument during the session simplified the task enormously for them. Subsequently, after a short discussion, they had to agree on a single score per instrument.

3.3 Data Processing

The data was organised on a worksheet in Excel (MS Office, 2018), containing the list of available instruments and their respective use per procedure. A '1' indicates at least one use, whereas a '0' indicates that the instrument was not used during that specific procedure. Missing data points were marked '-1'. If a tray was not available during the procedure, all instruments were marked '0'. When an unavailable tray was replaced by a similar tray or when a certain tray was deemed unnecessary in advance, the instruments on the missing tray were marked '-1'. The data was then imported to several models in Matlab (Mathworks, 2019) for further processing. A more comprehensive explanation of the Matlab models is given in the Appendix. Fig. 2 visualizes the data collection method.

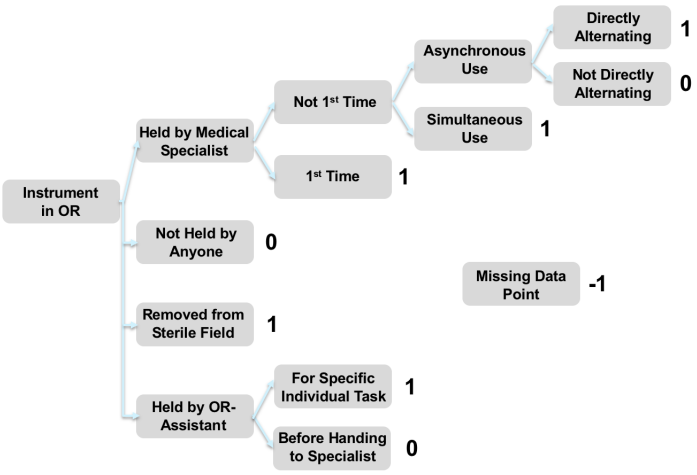

Figure 2: Decision Tree for Instrument Use Data Collection

The first model calculated the instrument use percentages for a chosen procedure type and showed the distribution of these percentages in a boxplot. A comparison between use percentages before and after the tray optimization was also shown in a boxplot. The second model showed the effect of different minimal use percentages on the tray composition. In this case, the minimal use percentage was defined as the use percentage above which an instrument was permanently kept on the instrument tray. A third model integrated the risk analysis into the second model, dividing the instruments in high risk and low risk categories. The sum of the two values in the third model, added up to the values in the second model.

The last model suggested a new composition of the trays, based on a chosen minimal use rate per instrument. For example, a minimal instrument use of 0% only removed the instruments that were never used, whereas a minimal use rate of 10% also removed instruments that were used in less than 10% of the observed procedures. A maximum amount of missing data, relative to the total size of the data, was also taken into account before suggesting the removal of any instruments. The healthcare institution put the removed instruments on a separate tray to be opened 'in case of', and eventually asked the medical specialists and OR-assistants to work without these items completely. Items that were rarely used could be isolated and put on separate trays as well, although this was not recommended in the case of the LUMC. The model was self-learning and allowed for exemption of critical instruments. The risk analysis, as described below, was used to index these critical instruments. These items could not be automatically removed to guarantee patient safety. Lastly, the model generated figures to compare tray contents based on the subjective recommendations (Specialist and OR-assistant opinions) and objective data.

3.4 Risk Analysis

Several types of risks had to be considered, before changing instrument tray composition in the operating theatre. This risk analysis tried to map the risks of specific missing instruments during the procedure. Nearly all of the described risks were related to patient safety. Due to time constraints, not all risks could be evaluated individually by the medical specialists. Therefore, they were asked to label the combined risk to patient safety for every available instrument, in case this instrument would be unavailable during the procedure. A scale of A - D was used, where A was no risk to patient safety, B was an acceptable risk (without permanent damage to the patient), C was an unacceptable risk (with permanent damage to the patient) and D was a critical or life-threatening risk. For example, a tool that is used often, but in a low-risk stage of the procedure, might be classified as a '2B' instrument. Similarly, a rarely-used instrument that is used to suture blood vessels might be classified as '1D'. Again, by performing this task in a group with at least three gynecologists, there was room for discussion to facilitate a unanimous decision.

The 'optimal' composition of medical instrument trays is presumably derived from a combination of objective data and subjective medical specialist and OR-assistant preferences. Acceptance of the new trays could only be achieved through consulting these professionals, whereas thorough reductions could be achieved more easily through discussions based on actual instrument use measurements. Also, high-risk items could only be removed after consulting the medical specialists. Therefore, the suggested tray compositions were iterated over different minimal use percentages. The total variability between the subjective and objective recommendations was used as a performance index for different minimal use percentages. For example, a minimal use percentage of 10% would be chosen for the third model, if the total variability between the specialist preferences and model outcomes was smallest for this percentage. The 'optimal' tray contents were based on the lowest number of instruments (lowest financial and environmental impact), without jeopardizing patient safety in any way.

3.5 Implementation and Evaluation

Over the course of this research, only the three trays for oncological laparotomies and only one new composition of these trays were tested during the evaluation phase. Thus, the evaluated tray contents were based on the combined information of instrument use rates, specialist preferences, OR-assistant preferences and risk analyses. The evaluation was done according to a 'plan, do, check, adjust' cycle. Firstly, for the plan-phase, a new tray composition was based on the use rates, for a minimal use percentage as described above (10% in this case). Secondly, the specialist preferences were discussed, based on these use rates. By challenging the initial ideas of the specialists with the measured use rates, even more instruments could be removed from the tray. To ensure acceptance of the new tray contents and to allow them to preserve responsibility on any patient safety concerns, the medical specialists could veto any suggested instrument removal. Thirdly, the suggested tray composition was discussed with the OR-assistants. This was an important step, as the OR-assistants work according to a specific methodology. Their requirements had to be met to ensure acceptance of the new contents on their side. These requirements included a request for even numbers of most instruments to facilitate easy counting and some extra items to help them perform tasks apart from the actual procedure.

For the do-phase, the new contents were assembled on a separate tray and registered in the T-DOC software of the CSSD. The removed instruments were also assembled on a separate tray to be kept inside the OR. This ensured availability of all instruments in case of urgent requests by the medical specialists. It could be unpacked in case the specialist unexpectedly needed one or more of the removed items. On the long term, the inventory on these redundant trays might be used to build other procedure-specific sets and increase efficiency. As before, individual instrument use was registered during the evaluation (or check-phase). This data could be used to theoretically check performance of other possible tray compositions as well. On top of that, any removed instruments

that were required by the medical specialist during surgery were registered on a separate instrument evaluation sheet. The goal of the evaluation phase was to register the number of instruments that had to be fetched from outside the OR during surgery. In case of a 'perfect' reduction, no extra instruments would have to be brought in during surgery, while a rigorous reduction in the total number of instruments on the trays was still accomplished. This, in turn, would minimize the number of unnecessary door movements and circulating nurse absence during the procedure, both of which had been previously identified as patient safety hazards. Therefore, the number of door movements and the impact of missing instruments on the total number of door movements, were also registered during the evaluation phase. Eventually, if necessary, some final adjustments were made during the adjust-phase, before standardizing the new tray contents. Fig. 3 shows the cycle of tray reduction efforts, including a combination of the different reduction methods and a feedback loop to evaluate and adjust any changes.

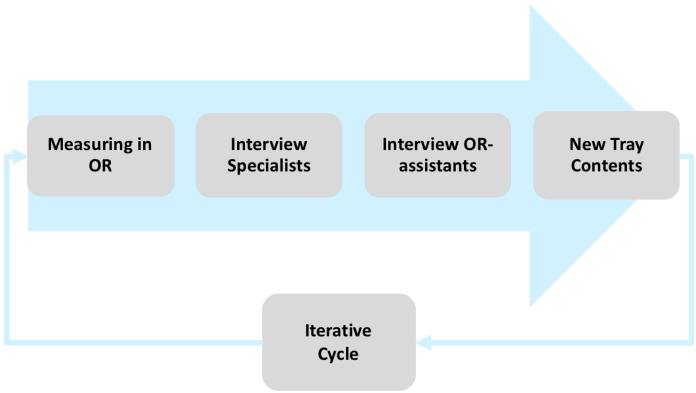

Figure 3: New Tray Optimization Methodology

3.6 Second Risk Analysis

The second risk analysis was used to quantify chances of missing instruments during the follow-up procedures, based on the different individual reduction methods. This analysis discussed the number of low-risk and high-risk instruments that would have been missed during the follow-up procedures, in case the reduction was based solely on one of the three old reduction methods (instead of a combination of all three methods).

4 Results

4.1 Instrument Use in the OR

Instrument use is observed for 28 procedures in the OR. All procedures are performed in the gynecology department. In total, 16 oncological laparotomies and 12 minimally invasive procedures were observed. Mean instrument use is 28.4% (SD=6.43%) for open surgery and 47.6% (SD=8.16%) for minimally invasive procedures. Fig. 4 shows a box plot for the instrument use percentage across the different procedure types. Both distributions show a single outlier. The average use percentage of the available minimally invasive instruments on the tray is much higher than the average use percentage of the abdominal instruments on the trays.

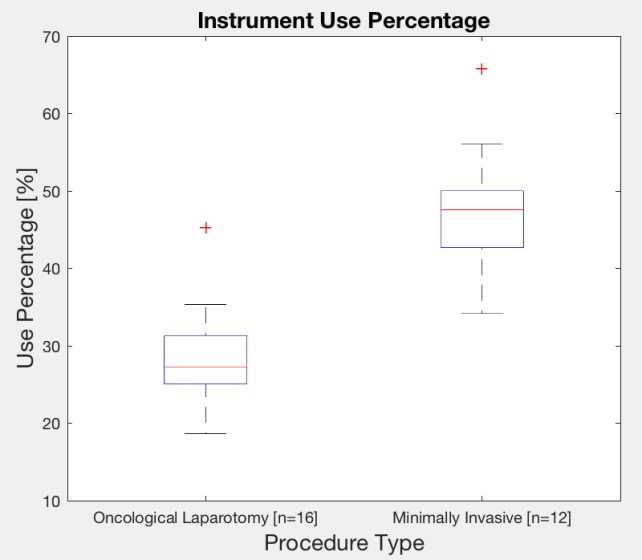

Figure 4: Use Percentage of Open and Minimally Invasive Surgical Instrument Trays

4.2 Objective Tray Reduction Based on Percentile Use

Actual instrument use is measured in the OR. Based on this data, the most conservative reduction effort would eliminate the instruments that are never used across the complete data set. Also removing instruments that are used in less than 5% of the procedures, by suggesting separately packing and fetching these instruments in times of need, would further reduce the total number of instruments. Fig. 5 and 6 show the results of this methodology for all minimal use percentages. The X-axis shows the minimal use percentage for an instrument to stay on the tray, whereas the Y-axis shows the number of instruments. Therefore, the line marks the new number of instruments for every minimal use percentage. A red 'X' marks the initial number of instruments, before any reduction efforts take place. For the oncological laparotomies, only removing the instruments that are never used over the duration of this research, will already decrease the total from 150 to 115 instruments. Considering a minimal use percentage around 20-25%, the new recommended tray composition would contain less than half the original amount of instruments.

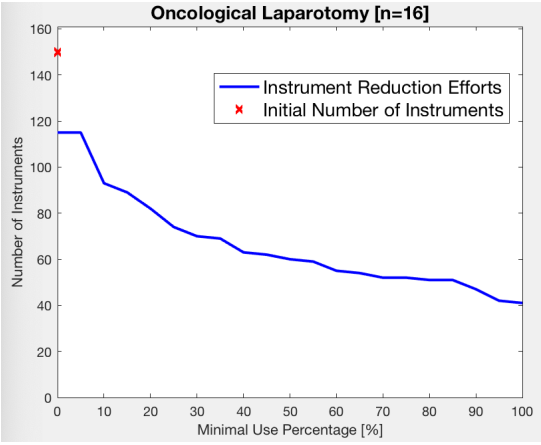

Figure 5: Instrument Reduction Efforts Excluding Risk For Oncological Laparotomy

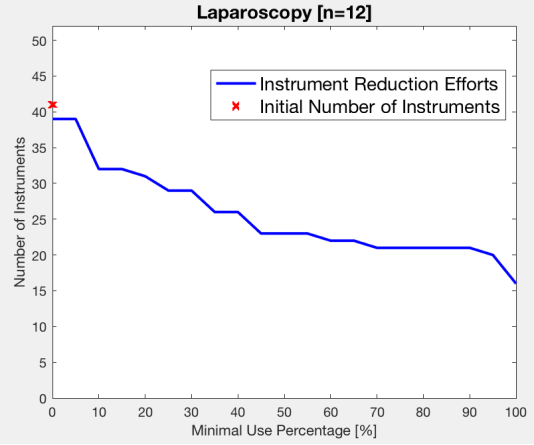

Figure 6: Instrument Reduction Efforts Excluding Risk For Laparoscopy

For every specific instrument, the medical specialists in the gynecology department were asked

to rate the risk to patient safety in case of unavailability during surgery. Risk C (permanent consequence) and Risk D (lethal consequence) instruments can not be removed from the tray without consulting the medical specialists. Incorporating these results, Fig. 7 and 8 show the reduced number of instruments, including high-risk items. Naturally, the number of high risk items can still be reduced in consultation with the medical specialists, in case of redundancy or replacement. In general, the two lines in these graphs add up to the single line presented in Fig. 5 and 6.

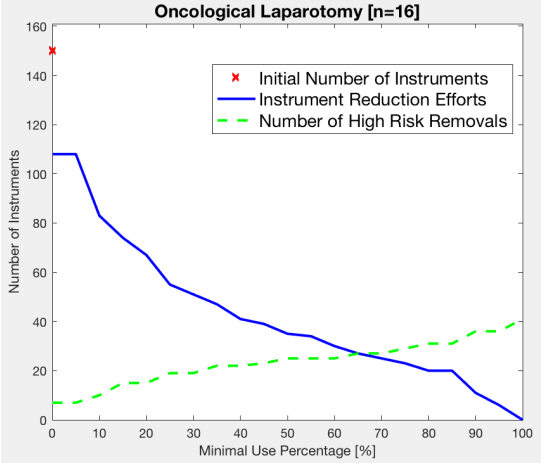

Figure 7: Instrument Reduction Efforts Including Risk For Oncological Laparotomy

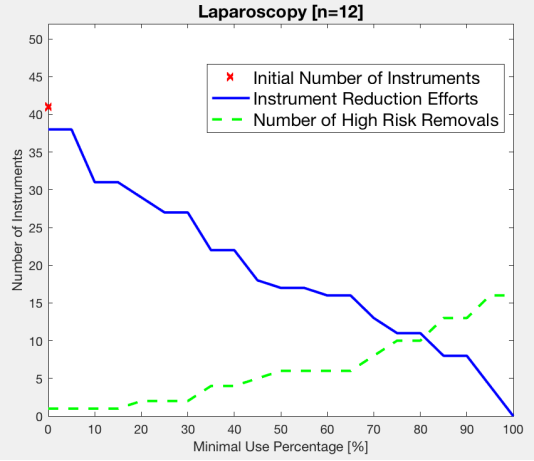

Figure 8: Instrument Reduction Efforts Including Risk For Laparoscopy

4.3 Comparison of Objective and Subjective Methods

As described above, three methods are considered to reduce medical instrument tray contents. Firstly, the medical specialists can decide themselves. Secondly, the OR-assistants should know which instruments are used, as they are familiar with all instrument tray contents (whereas the surgeons may only know the instruments they actually use) and hand every individual instrument to the physician during surgery. Lastly, measuring use rates objectively can also provide the necessary insights. This section will compare the different methods.

4.3.1 Between Medical Specialist and OR-assistants

New tray content suggestions by the medical specialists and the OR-assistants are compared first. Tables 1 and 2 show the new number of instruments based on their expert opinions, as well as the variability between their suggestions. According to the medical specialists, the number of instruments for oncological laparotomies and minimally invasive procedures can be reduced from 150 to 91 and from 41 to 27, respectively. Similarly, the OR-assistants think the number can be reduced from 150 to 113. However, they think we should not change the composition of the minimally invasive tray. For both types of surgery, their is a large difference between their opinions. Many instruments are only recommended on the tray by the OR-assistants. Fig. 9 and 10 show the similarities and differences between their opinions for both the abdominal and minimally invasive trays. 20% of the 150 abdominal instruments are only recommended by the OR-assistants, whereas only 5% of the set is only recommended by the medical specialists. They agree on the other 75%. Differences of opinion are even clearer for the laparoscopic instrument tray. The OR-assistants suggest that no instruments should be removed from this tray, whereas the medical specialists claim 34% (41 to 27 instruments) could be removed from standard rotation.

Table 1: Differences between Specialists and OR-Assistants Opinion, for Oncological Laparotomies.

Only Recommended by Specialist (S)	**New Number of Instruments (S)**	**Only Recommended by OR-Assistant (O)**	**New Number of Instruments (O)**	**Total Difference Between S and O**
5%	91 (-39.3%)	20%	113 (-24.7%)	25%

Table 2: Differences between Specialists and OR-Assistants Opinion, for Laparoscopies.

Only Recommended by Specialist (S)	**New Number of Instruments (S)**	**Only Recommended by OR-Assistant (O)**	**New Number of Instruments (O)**	**Total Difference Between S and O**
0%	27 (-34.1%)	34%	41 (-0%)	34%

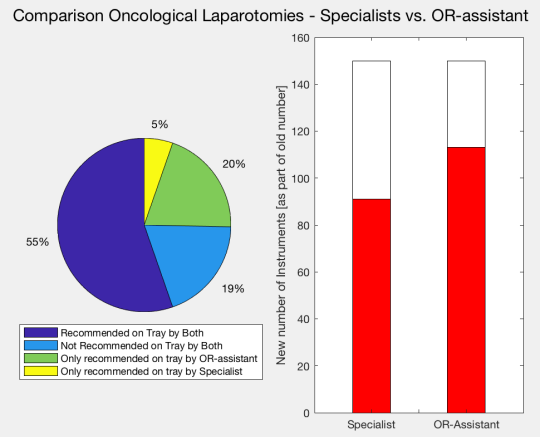

Figure 9: Comparison Between Both Subjective Reduction Methods for Oncological Laparotomies

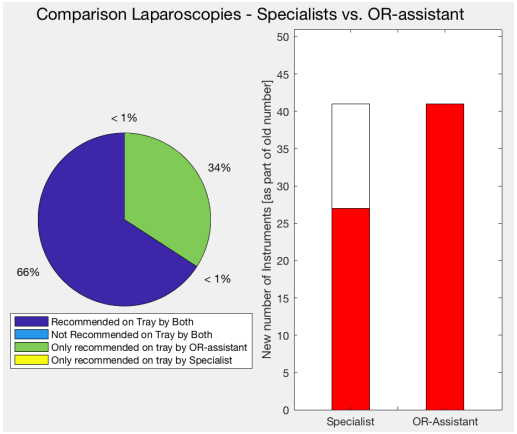

Figure 10: Comparison Between Both Subjective Reduction Methods for Laparoscopies

4.3.2 Between Medical Specialist and Objective Data

This section will compare the suggested tray compositions based on the use rates and the medical specialists opinion. Tables 3 and 4 show the newly suggested number of instruments on the trays, for different minimal use percentages. This minimal use percentage only influences the new 'objective' composition according to the use rates. The minimal variability between the two methods for the oncological laparotomies is located at a minimal use percentage of 10%, whereas the minimum is located at 35% for laparoscopic procedures. Around and above these percentages, the suggested tray composition is reduced more radically by the objective instrument use rates. Below these percentages, the medical specialists suggest a larger reduction. Fig. 11 and 12 give a visual interpretation of these results for a minimal use percentage of 10%. For the oncological laparotomies, it is clear that the use rates do not always correspond to the specialists suggestions. 9% of the instruments is only recommended by the medical specialists, whereas 10% of the instruments is only recommended by the objective data. Explanations for these findings are provided in the Discussion section.

Table 3: Differences between Data and Specialists Opinion, for Oncological Laparotomies.

Minimal Use Percentage	**Only Recommended by Specialist (S)**	**New Number of Instruments (S)**	**Only Recommended by Data (D)**	**New Number of Instruments (D)**	**Total Difference Between S and D**
0%	2%	91 (-39.3%)	18%	115 (-23.3%)	20%
5%	2%	91 (-39.3%)	18%	115 (-23.3%)	20%
10%	9%	91 (-39.3%)	10%	93 (-38.0%)	19%
15%	11%	91 (-39.3%)	9%	89 (-40.7%)	20%
20%	15%	91 (-39.3%)	9%	82 (-45.3%)	24%
25%	20%	91 (-39.3%)	9%	74 (-50.7%)	29%

Table 4: Differences between Data and Specialists Opinion, for Laparoscopies.

Minimal Use Percentage	Only Recommended by Specialist (S)	New Number of Instruments (S)	Only Recommended by Data (D)	New Number of Instruments (D)	Total Difference Between S and D
0%	0%	27 (-34.1%)	29%	39 (-4.9%)	29%
5%	0%	27 (-34.1%)	29%	39 (-4.9%)	29%
15%	5%	27 (-34.1%)	17%	32 (-22.0%)	22%
25%	7%	27 (-34.1%)	12%	29 (-29.3%)	19%
35%	7%	27 (-34.1%)	10%	26 (-36.6%)	17%
45%	15%	27 (-34.1%)	5%	23 (-43.9%)	20%

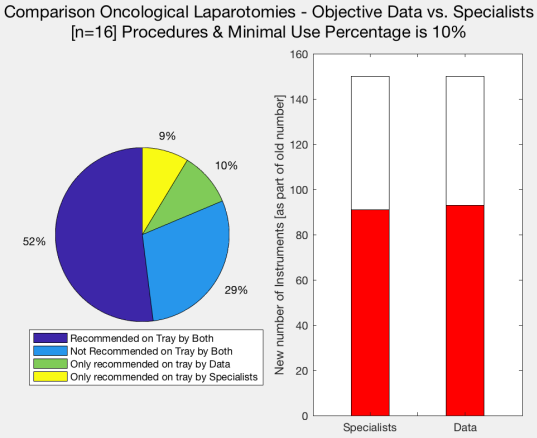

Figure 11: Comparison Between Data and Specialist Reduction Methods for Oncological Laparotomies

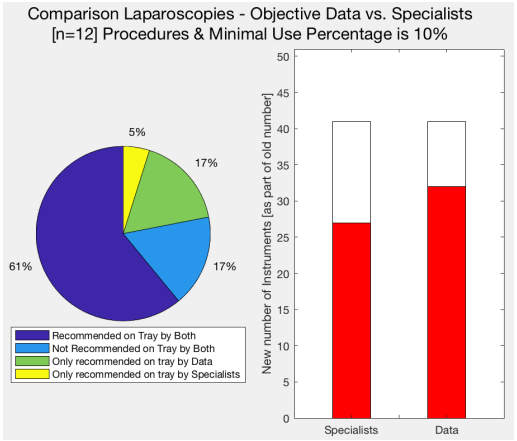

Figure 12: Comparison Between Data and Specialist Reduction Methods for Laparoscopies

4.3.3 Between OR-assistant and Objective Data

Lastly, the OR-assistants opinion will be compared to the use rates. Again, tables 5 and 6 show the results for different minimal use percentages. The minimal variability between the two methods is now at a minimal use percentage of 0%, indicating a more conservative reduction proposal by the OR-assistants. Fig. 13 and 14 give a visual interpretation of these results. In both cases, the large yellow area in the pie charts shows the number of instruments that are only recommended by the OR-assistants.

Table 5: Differences between Data and OR-Assistants Opinion, for Oncological Laparotomies.

Minimal Use Percentage	Only Recommended by OR-Assistant (O)	New Number of Instruments (O)	Only Recommended by Data (D)	New Number of Instruments (D)	Total Difference Between O and D
0%	9%	113 (-24.7%)	10%	115 (-23.3%)	19%
5%	9%	113 (-24.7%)	10%	115 (-23.3%)	19%
10%	21%	113 (-24.7%)	7%	93 (-38.0%)	28%
15%	23%	113 (-24.7%)	7%	89 (-40.7%)	30%
20%	27%	113 (-24.7%)	7%	82 (-45.3%)	34%
25%	33%	113 (-24.7%)	7%	74 (-50.7%)	40%

Table 6: Differences between Data and OR-Assistants Opinion, for Laparoscopies.

Minimal Use Percentage	Only Recommended by OR-Assistant (O)	New Number of Instruments (O)	Only Recommended by Data (D)	New Number of Instruments (D)	Total Difference Between O and D
0%	5%	41 (-0%)	0%	39 (-4.9%)	5%
5%	5%	41 (-0%)	0%	39 (-4.9%)	5%
15%	22%	41 (-0%)	0%	32 (-22.0%)	22%
25%	29%	41 (-0%)	0%	29 (-29.3%)	29%
35%	37%	41 (-0%)	0%	26 (-36.6%)	37%
45%	44%	41 (-0%)	0%	23 (-43.9%)	44%

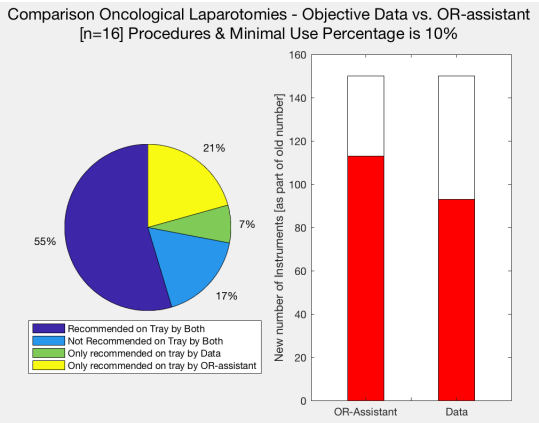

Figure 13: Comparison Between Data and OR-Assistant Reduction Methods for Oncological Laparotomies

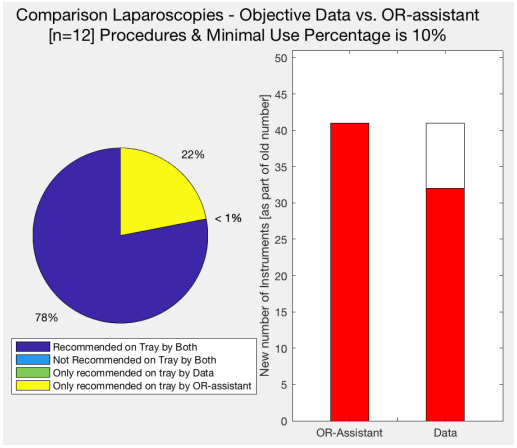

Figure 14: Comparison Between Data and OR-Assistant Reduction Methods for Laparoscopies

4.4 Reduction

Based on the combined information provided by the medical professionals and the measured use rates, the total number of reusable instruments for the oncological laparotomies, divided over three trays, is reduced from 150 to 95 (36.7%). The reduction is performed according to the described methodology in section 3.5. Fig. 15, 16 and 17 each show the remaining instruments after the reduction on the left and the removed instruments on the right.

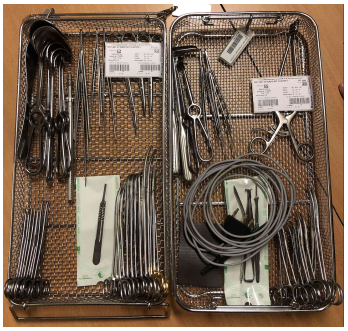

Figure 15: Basis Net Remaining and Removed

Figure 16: Gyn Net Remaining and Removed

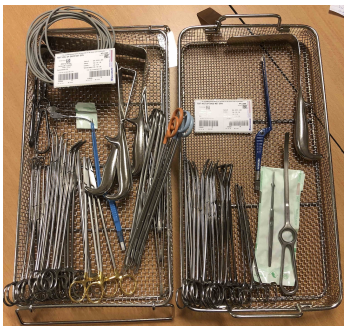

Figure 17: Onco Net Gyn Remaining and Removed

The reduction rates and the new number of instruments for these trays are shown in table 7. One instrument is added at the request of the OR-assistants, whereas 56 instruments are removed. A reduction percentage between 30 and 40% is reached for all trays. The goal was specifically not to separately pack rarely used instruments, as the storage spaces around the OR move to another floor after the renovation of the operating theatre. It will take more time to fetch instruments during surgery in the future. Therefore, a complete set is of the utmost importance to ensure future acceptance of the new tray contents.

The weight of the old and new tray contents is shown in table 8. The weight of an empty tray varies slightly, between 0.979 and 1.175 kilograms. In total, a weight reduction of 3.2 kilograms (31.3%) of instrumentation is achieved. Merging the instruments from 3 to 2 trays reduces the total weight of the instrument set for every oncological laparotomy by another kilo, to around 4.2 kilograms in total.

Table 7: The number of instruments before and after the reduction, as well as the reduction percentage.

Tray	Old Number of Instruments	Number of Added Instruments	Number of Removed Instruments	New Number of Instruments	Reduction [%]
Basisnet Cluster II	62	0	23	39	37.1
Gynaecologie Net	43	0	17	26	39.5
Onco Net Gyn	45	1	16	30	33.3
Total	150	1	56	95	36.7

Table 8: Table showing the old and new weight of the tray contents, including the absolute weight reduction and weight reduction percentage.

Tray	Old Weight of Tray Contents [g]	New Weight of Tray Contents [g]	Weight Reduction [g]	Weight Reduction [%]
Basisnet Cluster II	3055.1	2054.1	1001.0	32.8
Gynaecologie Net	3620.6	2280.6	1340.0	37.0
Onco Net Gyn	3683.8	2784.3	899.5	24.4
Total	10359.5	7119.0	3240.5	31.3

4.5 Evaluation

The new tray compositions are evaluated over three weeks (n=7) in the gynecology department. Fig. 18 shows the use rates of the instruments before and after the reduction. Mean instrument use increased from 28.4% (SD=6.43%) to 46.47% (SD=10.96%). The median has risen from 27.3 to 47.4%. There were no requests for removed instruments by either the medical specialists or the OR-assistants over the evaluation period. Therefore, no extra door movements were added to the total. Over the evaluation period, door movements per procedure were 33 (SD = 16.1) on average. The medical specialists reported 100% satisfaction with the new trays, as they encountered no surprises or missing instruments.

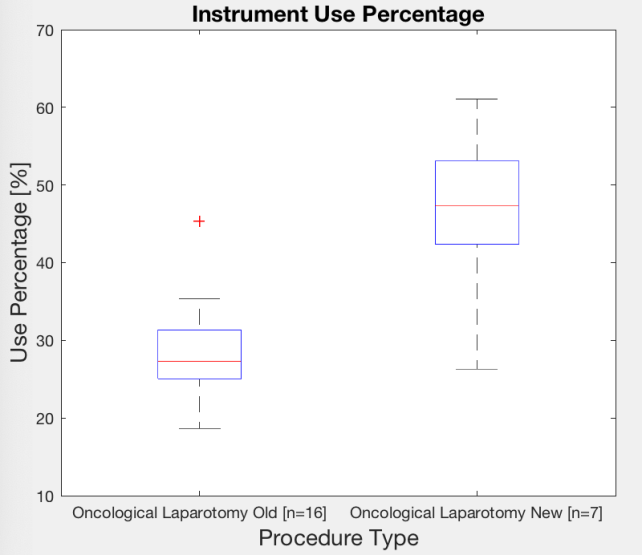

Figure 18: Old and New Use Percentages of Oncological Laparotomies

After the evaluation period, it was decided not to perform any additional changes to the tray contents. As the removed items made up approximately one-third of the total weight of the instruments, it was decided to combine the new sets on 2 trays instead of 3. The discarded items are

removed from the OR and kept in storage for now. Future reduction efforts could be based on an iterative process. Fig. 19 and 20 still show possible reduction possibilities of the abdominal trays, based on the evaluation period with the new tray contents. Six low-risk and nine high-risk items were not used once over the evaluation period. Choosing a minimal use percentage of 15% identifies another 27 items that could possibly be removed in consultation with the medical professionals.

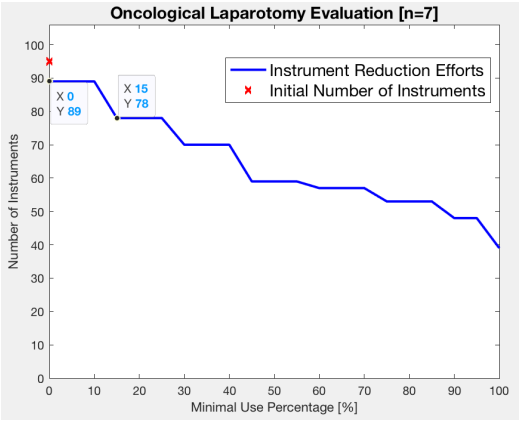

Figure 19: Future Instrument Reduction Based on Evaluation Excluding High-Risk Items

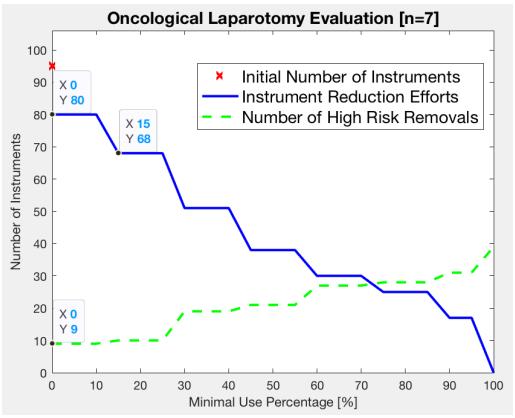

Figure 20: Future Instrument Reduction Based on Evaluation Including High-Risk Items

The results of the second risk analysis are shown in Tables 9, 10, 11 and 12. They show the suggested number of removed instruments (low-risk and high-risk) for different tray reduction methods. Note that these tables each show the results for a single reduction method. The first two tables give an overview of the minimal use percentages and the results based exclusively on the use rates. Also, the number of theoretically 'missed' instruments during the evaluation period is shown. For example, a '2' means that the medical specialist would have requested 2 instruments that were no longer available after the reduction, if this reduction was solely based on the use rates. Note that the model allows for exemption of high-risk items. In practice, only the low-risk items would have been missed. Lastly, the percentage of missed instruments as part of the total number of used instruments (n=309) is presented. A larger data set might reduce the missed instruments for a minimal use percentage of 0% even further. Based on the current data set, a 10% minimal use percentage would invoke a 3.24% chance of missing a specific low-risk instrument during surgery. The third and fourth table show the results for the subjective reduction methods. There would have been 2 missed high-risk items for both expert recommendations. However, the recommendation based on the opinion of the medical specialist would have induced 25 misses of low-risk items, whereas there would have been no low-risk misses according to the recommendation by the OR-assistant.

Table 9: Suggested Removal of Low-Risk Instruments Based on Use Rates with Associated Misses over [n=7] Procedures during Evaluation

Minimal Use Percentage	**Suggested Removal Low-Risk Instruments**	**Missed Instruments Low-Risk**	**% Missed of Total Number of Instruments**
0%	35	1	0.32%
10%	57	10	3.24%
20%	68	31	10.03%

Table 10: Suggested Removal of High-Risk Instruments Based on Use Rates with Associated Misses over [n=7] Procedures during Evaluation

Minimal Use Percentage	**Suggested Removal High-Risk Instruments**	**Missed Instruments High-Risk**	**% Missed of Total Number of Instruments**
0%	7	0	0.00%
10%	10	2	0.65%
20%	15	8	2.59%

Table 11: Suggested Removal of Low-Risk Instruments Based on Expert Opinion with Associated Misses over [n=7] Procedures during Evaluation

Expert Opinion of:	**Suggested Removal Low-Risk Instruments**	**Missed Instruments Low-Risk**	**% Missed of Total Number of Instruments**
Medical Specialist	56	25	8.09%
OR-Assistant	28	0	0.00%

Table 12: Suggested Removal of High-Risk Instruments Based on Expert Opinion with Associated Misses over [n=7] Procedures during Evaluation

Expert Opinion of:	**Suggested Removal High-Risk Instruments**	**Missed Instruments High-Risk**	**% Missed of Total Number of Instruments**
Medical Specialist	3	2	0.65%
OR-Assistant	9	2	0.65%

5 Discussion

This section will interpret the results from the previous chapter, discuss limitations of the research and briefly discuss the implications of hospital-wide tray reduction efforts. Lastly, it will provide guidance towards future research.

5.1 Interpretation of Results

Medical instrument use rates were objectively measured in the OR. Instrument use is clearly more efficient for the minimally invasive tray, for several reasons. Firstly, this tray composition has been created recently and was changed radically in march and august of 2018. The basic abdominal tray has also been created recently, but the gynecology tray (except for a minor change in 2010) has remained almost completely unchanged. The oncology tray has only had some minor revisions between 2010 and 2017. As a result, the abdominal trays contain a lot of outdated instruments which have never been removed. Secondly, the abdominal trays, especially the basic and gynecology trays, are used in a multitude of procedures, each requiring specific sets of instruments. Therefore, the LUMC should investigate whether their inventory and storage space allow for a more specific composition of the trays. Thirdly, minimally invasive instruments allow for fewer different procedural alternatives. Usually, the same instruments are used, regardless of patient anatomy and specialist preferences. The current, generic structure is very inefficient. Use percentages around 20 - 30%, as found for the abdominal trays, are in accordance with the use rates described by Stockert (2014) and Van Meter (2016) in previous research [18, 19]. They estimate the cost of decontamination to be at least $0.51 for a single instrument. Optimizing tray efficiency is therefore considered to be financially attractive.

The actual use rates show many instruments that are rarely used, visualized by the steep decrease in the top left plane of the figures in section 4.2. They should be removed completely, or packed separately to be opened in case of need. Due to distractions and wound infection risks, door movements have to be minimized, enforcing a (nearly) complete set in the OR during surgery [16, 22]. Therefore, it was decided not to separately pack rarely used items, but to focus on creating a reduced, but complete set. The division between high and low risk items could help to identify

the items which have to be discussed before removal. The OR-assistants are most conservative when it comes to reducing the number of instruments on the trays, followed by the objective measurements (at 0% cut-off). The medical specialists are willing to remove the largest amount of instruments. These differences can be explained by several considerations. This section will summarize why certain instruments would only be considered useful by either the medical specialist or the OR-assistant, or why they both feel the item would be redundant, whereas the data shows it was used anyway.

Why an instrument is only recommended by the medical specialists:

1. Due to the relatively small data set, some rarely used instruments were never registered during this research.
2. Actual use is overestimated by the medical specialists, compared to the OR-assistants opinion or chosen cut-off percentage.
3. Instrument may be used in another type of procedure, outside the scope of this project.
4. Nostalgia. Unwillingness to part with old methods.
5. Psychological aspects. Sometimes the specialists prefer to switch instruments, while having difficulty with a certain part of the procedure. Redundancy has a soothing effect on the mind and provides false certainty to the medical specialist. It may also concern a tool to clamp blood vessels. In case of a bleeding, the OR-assistant will usually open a separate set of vascular clamps, but the surgeon is still attached to the idea of direct availability.
6. Similarly, the medical specialist may not like to reduce instruments that 'belong together', like the Zeppelins (clamps and scissors), even though some of the items are not being used.
7. The medical specialist and the OR-assistant/data may not agree on which size of instrument to keep.
8. The medical specialist is 'right' to keep the item, whereas the OR-assistant or data is 'wrong' to remove it.
9. The recommendation may concern an instrument that is put on multiple trays (for example: blue clamps, kocher wound hooks, metzenbaum scissors). Recommendations may vary as to which tray is appropriate to keep the instrument on, in case all parties suggest removal from at least one tray.
10. The medical specialist may, subconsciously, take the OR-assistants preference for even numbers into account, even though they were specifically instructed to estimate actual use rates of individual instruments.

Why an instrument is only recommended by the OR-assistants:

11. Actual use is overestimated by the OR-assistants.
12. The OR-assistants favor redundancy. They feel responsible to have everything ready and do not like the idea of fetching extra instruments during surgery. They feel pressurized by the medical specialists in case an item is not directly available.
13. The OR-assistants can not always assess, from a medical viewpoint, whether certain instruments can be directly replaced by other alternatives on the tray. They want to keep all these items on the tray, whereas the medical specialists may suggest to remove one or more of these alternatives.
14. The OR-assistants work with even numbers, to facilitate easy counting. Even if the medical specialist only needs 1 or 3 of the same items, they will still suggest to put 2 or 4 of these items on the tray.

15. The OR-assistants are used to the current abundance on the instrument trays. For example, even if they only use 1 or 2 items simultaneously, they now feel they need all 4 of these items on the tray. They may use the other 2 items to prepare for actions later on in the procedure.

16. The instrument may only be used by the OR-assistant to clean surfaces before the procedure, clip labels or close the suction tube in between uses. The medical specialist has no knowledge of these activities.

17. The OR-assistant is 'right' to keep the item, whereas the medical specialist or data is 'wrong' to remove it.

Why an instrument is only recommended by the user data:

18. The instruments have not been grouped according to size. Data may suggest to keep all pairs of scissors, because they are all used from time to time. However, the surgeon may suggest 1 or 2 sizes to be sufficient, thus removing the others. This could be resolved by clustering instruments.

19. The instruments have not been grouped according to function. Some instruments can be used for exactly the same purpose. Clustering these instruments may help the data to use more of the reduction potential.

20. Redundant (high-risk) instruments that can not be removed autonomously.

21. The item is only recommended by the data if the medical specialists and/or OR-assistants underestimate its actual usage.

It is important to understand these considerations before undertaking any effort to reduce instrument trays solely based on user data input. Appendix E gives an example of a comparison between different reduction models, including some of the numbered reasons for potential differences. At this moment, even for a very large data set, it appears that some discussion with the medical professionals is necessary before changing tray contents. Even for a large data set and a minimal use percentage of 0%, the model would still not be able to reduce optimally, as it does not identify equivalent instruments. It would still keep both the 23 and 25cm scissors on the tray, because both are being used from time to time. However, the medical specialist is able to identify their similarity and should be able to suggest the removal of one size. Similarly, reducing based on OR-assistant recommendations is also safe, but not optimal in terms of reduction potential.

Changing to an autonomous instrument registration system would influence the education and current working methodology of the OR-assistants. Automatically counting instruments during and after the procedure would eliminate the need for (even) pairs of instruments. An intermediate step could be to 'group' similar instruments to pairs, in case the surgeon only needs 1 of each during the procedure. Until counting of instruments is done automatically, it is not possible to optimize the tray contents very often. The OR-assistants need time to get used to new tray contents. Implementing change in a complex environment like the OR takes time and should always be done step-wise and in consultation with all stakeholders. The specialists do not like to be surprised by any changes in their toolkit, even when these changes concern instruments they never use. On the other hand, the use rates can be used effectively to challenge the initial ideas of medical specialists and OR-assistants, in order to reduce unnecessary tray contents more radically and efficiently. The chance of refusal of the new composition by the medical specialists or the OR assistants is minimized by involving them throughout the complete process. Furthermore, chances of 'missing' an instrument during surgery are minimized through an evaluation of the new tray composition. The pilot case shows that the gynecologists know almost exactly which items are used, but sometimes need some encouragement to discuss this openly.

5.2 Limitations

The current study is subject to several limitations. Due to time constraints, the data set is relatively small. However, the methodology has been proven to work in a modern hospital setting. None of the stakeholders were blinded to the research objective. According to the Hawthorne effect, both surgeons and OR-assistants might have changed their behavior to influence research outcomes [17]. These changes may involve unnatural instrument use to ensure future availability. However, the research goal also motivated the entire department to consider environmental and financial impact of certain instrument decisions. Disposables were not always unpacked and extra trays were not always opened for a single extra instrument without some added hesitance and considerations.

Automatic data collection, for example by using RFID-tags on individual instruments, would certainly improve the scalability of the presented methodology. However, the data should incorporate some kind of timestamp, to ensure proper data-processing. Manual data-collection, correcting for asynchronous use and directly alternating use as described in the methods section on data processing, can only be replicated by automatically generated data when it has some kind of timestamp. OR-assistants often hold and present instruments, based on their expectations and experience, that ultimately remain unused. On the other hand, they perform certain tasks during surgery that require these instruments. Differentiating between these two options is going to be a challenge for automatic data generation and processing.

Quantifying risk is always prone to subjectivity. Unfortunately, for the first risk analysis, it was necessary to consider every individual instrument. Due to time constraints and the very busy schedule of the gynecologists, this enforced a rather concise approach. The first risk analysis methodology provided the valuable insight that risk- and use interpretations of the specialist based on pictures and official instrument names are very unreliable. A second attempt, using the actual instruments in a group discussion, provided much more reliable data. The second risk analysis took instrument use rates from the follow-up procedures to check theoretical performance of separate tray optimization methods. Instrument use by the gynecologists may have been influenced by the new tray contents, reducing reliability of the results. However, as the new tray composition was not specifically discussed with the end-user before implementation, instrument use is not expected to have changed much. Also, the medical specialists were requested to ask for instruments as usual, knowing all the items were available on stand-by during the follow-up procedures. The number of theoretical misses during evaluation is depicted in the results. However, it can not be guaranteed that these instruments would indeed have been missed, as they might have just as easily been replaced by another, equivalent instrument.

Suggestions based on objective data did not perfectly fit the specialists opinion for any minimal use percentage. Therefore, the minimal variability between these suggestions provides an indication for the optimal cut-off point, but is still not completely reliable for the reasons described above. This research is still the first to present a methodology to find such a cut-off percentage, instead of just choosing one randomly.

The second risk analysis shows a rather large chance of missing an instrument during surgery for higher minimal use percentages (10 or 20%). However, combined with the input from the medical specialists and OR-assistants, similar reduction percentages have been reached without ever missing an instrument during surgery. This indicates the need for a more comprehensive model, incorporating artificial intelligence to mimic expert considerations. Such a system should be able to group equivalent instruments and group instruments that are always used simultaneously. Based on the methodology described in this research, this model would create a list of all necessary instruments for every specific procedure. This list could be incorporated in an optimization algorithm, to construct the cost function for optimal instrument tray contents. In this case, the cost function would minimize the percentage of unused instruments on a tray for a given procedure (efficiency), while the constraints would be defined by the maximum weight per tray, maximum storage space,

total instrument inventory and investments, necessary instruments for every procedure, etc.

5.3 Environmental and Financial Impact

Apart from the advantages in the OR, such as a reduction in physical strain, setup time and OR waste, most of the advantages associated with tray optimization take place around the CSSD. In case of the LUMC, the in-house CSSD sterilizes around 85000 trays of instruments per year. A single tray is divided over multiple trays before washing/disinfection, to ensure maximum exposure of instrument surfaces to water and detergents. Therefore, a significant reduction in the number of instruments will also significantly reduce the number of washer/disinfector cycles. This will not only decrease water, heat, detergent and electricity consumption, but may even be cause to reduce the number of machines itself. Currently, the LUMC has six operational washer/disinfectors machines. Considering a 10 to 30% reduction in the rotation of instruments, 1 or 2 machines might be redundant. Water and detergent use are expected to decrease almost linearly with the number of instruments. Energy consumption (electricity and gas for heating) should be measured during machine idle time, but is expected to decrease significantly as well. A more detailed calculation of costs and environmental impact is discussed in the appendix.

The number of trays that have to be sterilized per year is not expected to change much. Some large procedures may combine 3 reduced trays into a new 2-tray set, but, in general, the reduction will only effect the weight of the load during sterilization. McGain et al. (2017) suggest sterilization equipment uses 20% of the total water consumption and 40% of the total electricity consumption during machine idle time. Therefore, changing load weights and number of cycles will only influence the other 80 and 60%, respectively. They further suggest a linear relationship between load weights and electricity consumption, but no clear relationship between load weights and water- or steam usage [15]. This may be due to a preset amount of water for every cycle and a relatively large steam consumption for vacuum pulsing and filling of the steam chamber. Again, actual measurements around the CSSD at the LUMC might provide more detailed results. In general, a reduction in use of electricity, water and steam should be related to a reduction in costs and CO2-equivalent.

Organizing the instruments on the trays before machine washing, inspecting functionality afterwards and assembling them in their original composition before packaging and sterilization, comprise a large part of the daily CSSD-employee tasks. Thus, a large percentile reduction in the number of instruments per tray is expected to make a similar impact on the required CSSD-personnel hours. Stockert et al. (2014) describe a reasonable good linear fit on the relation between the number of instruments on the trays and the total time to decontaminate and pack these trays [18]. They measured instrument decontamination and packing times to be 4.02 and 12.51 seconds, respectively. These times are directly related to personnel costs. Furthermore, costs of maintenance, repair and replacement of instruments will decrease as well. Less redundant items in an instrument tray will reduce the chances of instruments damaging each other during transport. Ultimately, significant cost reductions can be associated with hospital-wide tray optimization. Using reusable instruments more efficiently might close the financial gap to disposable alternatives. As a result, returning to reusable alternatives may be a great way to improve sustainability around the OR, reducing wastes, resources and transportation of disposables enormously.

5.4 Recommendations

The presented methodology can be used to form a list of required instruments per procedure. This list may be used to scale the idea to optimize tray contents for all departments across the hospital. Hospitals should not only optimize tray contents for the current tray compositions, but also consider building separate, effective trays for common procedures and removing generic ones. The OR-assistants in the LUMC have already begun forming a separate tray for vaginal hysterectomies,

using the instruments that have been removed from the oncological and gynecological trays. The gynecologists have also suggested to focus on a separate tray for the DaVinci robot-assisted procedures, as all the regular instruments on the current laparoscopic tray are not designed for robotic surgery. On the long term, the hospital should strive towards individually tagged instruments. This will not only provide the necessary data for autonomous tray optimization efforts, but also improve traceability. Being able to distinguish between specific instruments that have been used for specific patients and being able to monitor the phases of the procedure through instrument usage will certainly be part of the OR of the future.

Future research should also focus on measuring the actual financial and environmental improvements of instrument rotation and inventory reductions. Very few articles describe measured water and electricity use of sterilization equipment and no such articles have been found for washer/-disinfector machines. McGain et al. (2016 & 2017) describes the inaccuracy of estimations based on manufacturer specifications [14, 15]. Reliable results will have to be based on measured energy consumption of the machinery. Objective measurements are also needed to estimate a reduction of CSSD-personnel reliably. Lastly, the average cost of sterilising a single instrument (including depreciation and replacement) may not apply for the instruments on the trays that are never used. Again, keeping track of actual costs and collecting data is necessary to make valid assumptions about these numbers.

6 Conclusion

In general, this research maps the large differences between objective and subjective tray optimization methods. Both provide essential input in any effort to substantially reduce contents of medical instrument trays without harming patient safety. A combination of objective data and expert considerations can lead to a significant reduction of the amount of unnecessary items in the medical instrument cycle. A pilot study at the gynecology department of the LUMC shows the enormous potential for efficiency improvements in instrument usage.

Recommendations of OR-assistants for tray optimization are most conservative, followed by a user-data approach. Medical specialists suggest the most radical reduction. Currently, recommendations based on use rates can only be used autonomously when they are based on a minimal use percentage of 0%, removing the items that have never been used. This yields a save, but conservative reduction. More radical reductions are achieved through clustering of instruments. This involves collaboration with medical specialists and OR-assistants, until a model is able to mimic this expert input. Creating a list of needed instruments for every procedure is the first step towards a complete, hospital-wide restructuring of all instrument trays.

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Appendices

A Observations in the OR

A.1 Communication between Departments

Communication between OR- and CSSD-personnel is scarce. However, both departments are connected through the same in-house medical instrument cycle. This lack of communication creates tension between the departments and pressurizes efficient teamwork. Both the OR and the CSSD have to deal with the mistakes and shortcomings of the other department, creating a negative atmosphere. For example, employees of the CSSD are annoyed by the many instruments that have been put on the wrong tray after use. Sorting these instruments at the CSSD and returning them to the wright tray is time-consuming. OR-assistants do not think about these consequences and are pressurized to clean the OR quickly before the next patient arrives. Also, instruments go missing from time to time. One common example is the cleaning clamp, used before any procedure. After use, this instrument is thrown in the waste bin, where it should be collected by the circulating nurse. However, engaged in other tasks and activities, they often forget. The CSSD is responsible for the delivery of complete sets to the OR, which is why missing instruments cause unnecessary stress.

Similarly, OR-assistants and medical specialists have their own frustrations. They often complain about the reduced functionality (blunt edge or rough hinge of scissors and other tools) of instruments. They label these instruments to be functioning improperly, but, according to them, receive the same defective instruments for the next procedure. The CSSD reconsiders these requests and checks whether they agree on the issue and have budget available for repairs or replacements. In both cases, direct lines of communication on such issues or periodic meetings to explain and discuss all considerations, could help to improve teamwork. Combining the managing positions of both departments has been an important step to solve these issues. Increasing knowledge of and appreciation for the efforts of the other department, might improve communication and teamwork. Lastly, the communication between the departments is severely impeded by the differences in terminology. For example, the "atraumatic clamp hysterectomie, 27cm bent tip" is called "Oberholt" by the OR-personnel, whereas the CSSD uses the official name. Many items have several names, creating translational issues between the departments.

A.2 Communication within OR

Communication within the OR, though abundant, is also provoking several issues. Firstly, requests from the medical specialists before the procedure regarding the required instruments are not always clear and concise, forcing the OR-assistants to make assumptions and choices autonomously. The OR-assistants are often correct in their judgments, but not always, causing them to become overcautious in their preparations. In practice, this results in several unpacked disposables and instrument trays, which could have remained unopened through clear communication. Inconsistent behavior by the medical specialists further increases their caution. For example, the OR-assistants might discuss their frustration with the complete lack of consistency in the demands of a certain gynecologist. Not knowing what specific item he or she will request this time, they make sure to have all alternatives on standby, causing extra environmental and financial impact of the procedure.

Secondly, during the procedure, the medical specialists may also be vague or inconsistent with their requirements. As multiple sizes of most instruments are available, just asking for a pair of scissors may cause confusion. Again, this allows for interpretation by the OR-assistant. Interestingly, the size they hand is usually accepted, indicating involvement of the OR-assistant in the medical aspects of the procedure, but also a possible redundancy of other sizes of instruments. The medical specialist does not often know the exact contents of the trays, leading him or her to ask for instrument types without being specific. We call this the: "Do you have something like

a..." mentality. Again, vague communication and room for interpretation by the OR-assistant may lead to improper instrument use (misuse) and abundance on the instrument trays.

Clear demands do not solve all of these issues. Sometimes, the physician may ask specifically for the wrong instrument in advance. For example, they might ask for a tool (short scissors) that is not suitable for the type of patient (large patient) they will be treating. In these cases, the OR-assistant should discuss any concerns he or she has with the proposed instruments, before opening every tray or disposable in advance. Communication is key, combined with clear procedures regarding instrument requests.

Finally, a lack of communication between specialists from different departments also obstructs efficient teamwork. Throughout this research multiple procedures required the assistance of a general surgeon, plastic surgeon and/or urologist. The gynecologists did not always involve the other specialists beforehand. Their unexpected involvement causes stress and a negative atmosphere in the OR, as they did not have the chance to properly prepare their part of the procedure.

A.3 Procedural Issues

The OR is a very complex and dynamic environment. Standardized procedures are sometimes difficult to implement, because unexpected events take place very regularly. However, improvisation can be hazardous to patient safety. Several examples stood out when it comes to a clear lack of standardized procedures. Firstly, due to a lack of data and technological infrastructure, many safety-improving tasks like the counting of instruments, needles and gauzes have to be performed manually by the OR-assistants. Counting these items is important to make sure no foreign objects have been left inside the patient. However, a recount is only performed in case of missing items, creating a weak spot for false positive counts. Not only do OR-assistants have to memorize the contents of every tray, but they should also count to check the completeness of these trays before the end of the procedure. To register instruments going on and off the trays automatically during surgery would eliminate this manual way of counting and reduce the chance of a human error in the process. Also, it would allow us to put uneven numbers of instruments on the trays as well, based on the actual use during the procedure. Currently, most instruments are presented on the tray in even numbers. OR-assistants are able to check very quickly whether one of the instruments is unaccounted for at the end of the procedure. However, as this is not the same as an actual count based on the contents of the tray, both instruments could be lost during surgery. Relying on this methodology is therefore potentially dangerous.

Air quality is strictly guarded within the OR and can be defined using the number of unwanted particles in the air. Door movements during surgery have been associated with extra particles, thus comprising patient safety. Tearing paper and cardboard from packaging materials should also be banned inside the OR, because of its effect on air quality. Although the air around the patient is guarded more strictly by the ventilation system in the OR, minimizing particles should always be the goal. In general, between 30 and 40 door movements were normal for any oncological laparotomy during the test period. Employees did not hesitate to come in or leave as they pleased during any phase of the procedure. Other departments are more strict regarding these matters, indicating the need for strict rules. Another such rule is the maximum of 12 people in the OR during surgery. This number has been exceeded many times. Again, it should be clear that these rules have been created for a reason. Ignoring them is unacceptable. It should not be socially awkward to remind anyone to step outside in case the maximum number of staff has been exceeded.

OR-personnel has no knowledge of the financial consequences of their actions. Sometimes, the medical specialist suddenly requires extra instruments during surgery. Quite often, this situation can be solved by fetching disposable or reusable instruments. The disposable alternative (for example, a Ligasure), might be compared to opening an extra tray of instruments (for example, the Oncology tray). The OR-assistant will usually pick the disposable alternative, because it feels unnatural to open a complete set of instruments if they only need one or two items. However,

financially speaking, the Ligasure is more expensive than the decontamination of a single tray. It might help to give insight in these numbers, so the OR-staff can weigh financial and environmental costs in the choice between different alternatives. Likewise, a choice between equally safe, equally expensive and equally functional anesthetics might be made based on environmental impact of the materials. In case of the HIPEC procedures at the gynecology department, the wound spreader needs an extra support on the operating table. Current procedure is to open a complete wound spreader tray, just to use this single support. Physicians and OR-assistants need tools to consider alternatives objectively.

Misuse of instruments is common in the OR. Delicate scissors are used to cut thick sutures or wires of disposable electronic equipment. These instruments wear quickly, leading to many complaints regarding instrument quality during surgery. It might be wise to put a pair of (non-sterile) wire cutters in the OR, just to cut the cables at the end of the procedure. Generally speaking, OR-personnel should develop more feeling for the delicacy and value of certain instruments. The CSSD might advise which items wear down easily. Subsequently, these items can be used more cautiously in the future.

Other procedural issues arise from scheduling mistakes. Incidentally, patients do not arrive on the appropriate date. The ward failed to inform the OR of their absence, causing a complete OR team to arrive the next morning with no patient to operate on. Early detection of mistakes can help to limit negative consequences. Also, the scheduling department does not seem to take average procedural times of different medical specialists into account. They may all suggest that a certain procedure takes around three hours to perform, but some work faster than others. This should be corrected to increase efficiency and reduce overtime. Two other inconsistencies are found to happen quite regularly. Firstly, the order of procedures in the schedule somewhat influences the outcome. 2 laparotomies are followed by 1 laparoscopy one time, while the laparoscopy is followed by 2 laparotomies the other time. The first scenario often results in shifting the last patient to another date, whereas the second scenario usually means overtime. Secondly, the schedule might have accounted for an abdominal procedure, while the surgeon suddenly decides to do a laparoscopic approach. A similar laparoscopic procedure takes longer, which caused another patients appointment, already waiting in the holding department, to be cancelled. Measuring and evaluating planned and actual procedural times may improve the system over time.

Lastly, some other small issues were discovered during the research. Instrument satisfaction forms, which are filled out inside the OR, are eventually returned to the CSSD and recycled. However, these forms may have been contaminated during surgery and should not be recycled. Secondly, tissue samples are wrapped in small pieces of paper without lead threading. These pieces of paper are difficult to track and count, and should be banned.

A.4 Psychological Factors

Several psychological considerations are also important while observing behavior in the OR. Firstly, considering both the medical specialists and OR-assistants, it seems only the presence of a certain instrument inside the OR creates demand for this instrument. In this case, instrument use is not the same as instrument necessity. He or she might just as easily use another instrument in case of unavailability. This is why the OR-assistants and user data can never reach the full reduction potential without consulting the physician. Looking at the subjective opinions of the OR-personnel, it is important to address their fears and habits. If either the specialist or the OR-assistant is not confident about and supportive of the instrument reduction, he or she might block the implementation altogether. For example, the OR-assistant is afraid to do more work. At this moment, they have been taught to work with even numbers of the same instruments (2, 4 or 6 of everything), to easily spot missing items and to facilitate an easy count at the end of the procedure. Also, it helps them to do a swift transition when they are relieved by a colleague. However, many of these instruments are only needed once, 3 times or 5 times. Forcefully changing their way of working,

especially if they are afraid to make mistakes during the instrument count or to be reprimanded in case of incomplete instrument sets, will not produce lasting solutions.

OR-assistants have the tendency to hand a clean instrument to the medical specialist. For example, four equal items may all be handed to the physician in turn, even when they need only one at a time. Future data, derived from automatically measuring instrument use, has to be corrected for this type of behavior. The OR-assistants and postgraduates are often rearranging or toying with instruments during the procedure. This type of behavior should not be recorded as official instrument use. Personal preferences of different OR-assistants also influence objective data collection. They use different items to clamp suction tubes, disinfect skin surfaces before the procedure and clamp labels of gauzes and needles. These items are not considered to be necessary, because a multitude of different items can be used for the same purpose.

In other cases, the medical specialists are having difficulty completing a specific part of the procedure. Asking for a different, but similar or even equal instrument 'resets' the mindset and often leads to sudden success. Reducing tray contents may not interfere with the confidence the medical specialist has in the variability of the tray. However, there is a false certainty in the current abundance of instruments. Medical specialists may find it comforting to have many items to choose from, while in fact these items only increase misuse, possibly even compromising patient safety. The same phenomenon occurs when a tray of instruments is not available. It could be missing, unsterile or incomplete. Usually, a similar tray is available, with slightly different contents. The medical specialist easily accepts the new tray, but is equally hesitant to remove the other (apparently redundant) items from the old tray.

People always have a tendency to avoid conflict. An example is the Lean smiley-sheet, meant for the OR-personnel to indicate their satisfaction with the instruments (as they were delivered by the CSSD-personnel). They can only choose between a 'satisfied' happy face, and a 'not satisfied' sad face. The OR-assistant is usually hesitant to mark the sad face, even when certain trays are missing, multiple instruments do not function properly or previous complaints have not been processed.

Finally, the successful pilot case at the gynecology department also increased awareness around the OR. Suddenly, some of the more experienced OR-assistants are enthusiastic to contribute to the sustainable use of reusable instruments. They are undertaking steps to continue the project across the rest of the department, while the momentum lasts. Again, this shows the importance of active stakeholder involvement throughout any process of change. It is the only way to ensure lasting change with continued efforts to improve.

B Background CO2 en costs

Apart from the previously described advantages of tray optimization around the OR, such as a reduced physical burden, less waste and clutter, and a reduced chance of misuse of instruments, most of the financial and ecological consequences of tray optimization take place in the CSSD. The following section will, based on other research and assumptions, try to partially quantify these consequences for the different steps in the medical instrument cycle. Although a reduction of 37% was achieved over several trays in the gynecology department, it is impossible to extrapolate this number to a hospital-wide reduction potential. Other literature describes reduction percentages anywhere between 2.2% and 92.7%, for different tray optimization efforts. The LUMC decontaminates 85000 sets every year, excluding separately packed items. These sets contain 17.8 instruments on average. However, due to the high variability, they may contain anywhere between 5 and 100 instruments. Also, some trays may be sterilised multiple times a week, whereas others remain in storage for months or even the entire year. According to Stockert et al, instrument use rapidly declines with an increasing number of instruments per tray, indicating a larger reduction potential (both relative and absolute) for larger instrument sets [18]. More measurements in the OR and involvement from different departments are necessary to estimate the total reduction potential of the instrument inventory. For now, a wide range of 10% to 30% reduction potential is used to estimate several of the cost reductions below. Using the average of 17.8 instruments per tray and a total of 85000 decontaminated sets, the estimated number of items in the medical instrument cycle is set at 1.5 million per year, excluding separately packed items.

B.1 Washer/Disinfector Cycles

A reduction in the total throughput of items in the medical instruments cycle is believed to have the largest impact on natural resource consumption around the washing and disinfection processes. This assumption is based on the fact that large instrument sets are divided over multiple trays for the washing and disinfection processes. The cleaning and disinfection of medical instruments happens in a single, combined cycle of the washer/disinfector machines. Some of these instruments go through pre-cleaning first. At the LUMC, 1 pre-cleaning device and 6 regular washer/disinfectors are available. In 2018, 4380 pre-clean cycles and 12865 regular cycles have been recorded. These 17245 cycles used a total of 3449 cubic meters of reversed-osmosis (RO) water (200L per cycle) and 690 cubic meters of softened water (40L per cycle). The washer/disinfectors therefore used 54% of the total of 6336 cubic meters of RO-water in the CSSD over 2018. There are no records of the yearly softened water consumption of the rest of the department.

Based on the assumption that we can reduce the capacity of washer/disinfector machines from 6 to 4 machines, due to the current surplus and future instrument tray reductions between 10 and 30%, the total machine consumption will decrease by approximately one-third. In case of the RO- and softened water, this reduction does not influence the pre-cleaning cycles. This yields an 858 m3 reduction in RO-water usage, which is a 13.5% reduction on the total CSSD consumption. Softened water consumption is reduced with 171.5 m3. RO-water is priced at 5.28 € per m3, softened water is priced at 1.56 euros per m3 and water disposal costs are set at 0.92 euros per m3. The cost reduction C of washer/disinfector water consumption alone can be calculated as follows:

$$C = (2573 * 6.20 * \frac{1}{3}) + (515 * 2.48 * \frac{1}{3}) = 5743\, euros \tag{1}$$

Similarly, a total of 351 tons of steam was used to heat the water inside the RO-boiler. 40% ((12865/17245)*0.54) can be attributed to the regular cycles of the washer/disinfectors. Priced at 0.043 € per kg of steam, the total costs add to:

$$C = 351 * 0.043 * 0.40 * 1000 = 6080\, euros \tag{2}$$

Costs associated with the machines themselves are also non-trivial. Washer/disinfectors are priced around 100000€, with a depreciation of 10000€ per year. Therefore, yearly capital cost

reductions, after the next investment (machine purchase), can be estimated at 20000€ per year. Maintenance costs of these machines can be divided into preventive and corrective maintenance. Preventive maintenance is contracted at 3000€ per machine per year, whereas corrective maintenance averaged at 5216 per machine per year over 2014 and 2015. Total, yearly savings in depreciation and maintenance costs are therefore estimated to be:

$$C = 2 * (10000 + 3000 + 5216) = 36432\, euros \tag{3}$$

Lastly, a 10 to 30% reduction in the total instrumentation throughput affects the pre-cleaning water- and steam consumption as well. The 4380 pre-clean cycles use a total of 876 m3 of RO-water and 175 m3 softened water. Cost reductions are therefore estimated to be between 590 and 1760€, as shown in the equations below.

$$C = 0.1 * (876 * 6.20 + 175 * 2.48) = 590\, euros \tag{4}$$

$$C = 0.3 * (876 * 6.20 + 175 * 2.48) = 1760\, euros \tag{5}$$

B.2 Personnel Costs

Every individual instrument is handled by a CSSD-employee at least twice. Upon arrival at the CSSD the items are disassembled and placed in different trays for the washer/disinfector cycle. Secondly, before packaging, all items are assembled, inspected and placed in the 'normal' tray layout. These activities comprise a large part of the manual labor of the CSSD employees. Stockert et al. timed these activities to be 4 and 12.5 seconds, respectively. The same 10 to 30% reduction therefore induces a CSSD-personnel demand reduction P of:

$$P = 0.1 * \frac{16.5}{3600} * 85000 * 17.8 = 700\, hours \tag{6}$$

$$P = 0.3 * \frac{16.5}{3600} * 85000 * 17.8 = 2080\, hours \tag{7}$$

As a full-timer works approximately 1830 hours a year, a 26% reduction of total instrument throughput equals 1 employee of the CSSD, only taking instrument decontamination and packaging into account. This is probably gravely underestimated, as a number of other factors also has a negative influence on the required working hours. A smaller workplace, storage space and a reduction in the number of logistic issues associated with a larger inventory, will also contribute. The 'Sterilisatie Vereniging Nederland' estimates personnel costs to be between 50 and 60% of the total CSSD budget, which is in accordance with the numbers at the LUMC. Thus, a significant reduction in necessary manual labor around the department has a large impact on the total financial statements.

B.3 Instrument Costs

Naturally, a reduction of instrument inventory will lead to significant cost savings as well. Van Straten Medical estimates the average costs of maintenance, repair and replacement of instruments to be around 2€ for every single use. Assuming a 10 to 30% reduction in instrument rotation, these costs would be between 300 and 900 thousand euros. These numbers are probably too high, because repair and maintenance costs are lower for rarely used instruments. However, instruments are easily damaged in larger sets and the decontamination processes. Follow-up research should strive to specify these costs more reliably. In the long run, not having to replace or repurchase the removed instruments will certainly reduce costs significantly.

B.4 Additional Costs

This concise estimation disregards possible effects on the sterilisation process. According to McGain et al, electricity use will probably decrease with a decreased load weight, but steam (heat) and water consumption will only drop significantly with a reduced number of cycles [15]. Besides, the hospital should strive towards less steriliser capacity, as the constant steam pressure on the system and the high energy usage during idle time are responsible for a large part of the energy consumption.

At this moment, total electricity, heat, ventilation and gas consumption can only be roughly estimated based on the size of the department in square meters. Changes in these values based on the reduction of the number of instruments can not be estimated reliably. More detailed energy consumption measurements of different machines are necessary for future cost reduction calculations. Lastly, smaller instrument trays, less packaging tables, smaller walking distances across the department, faster throughput of trays and less chemicals and detergents will all reduce costs around the department, directly or indirectly. Future research should try to quantify these advantages. Therefore, the influence of these factors on the environmental impact remains unknown as well.

B.5 Environmental Impact

Although incomplete, some of the described consequences of tray optimization can be related to a reduced environmental impact, measured as a CO2-equivalent. The environmental impact of the air quality system around the CSSD has been measured to be 171 tons of CO2. A smaller workplace, due to a reduced throughput of instruments, could reduce this number slightly.

A reduced washer/disinfector capacity leads to total water savings of 1146.5 m3 (RO-water, softened water and steam), with an added 105 - 315 m3 of pre-cleaning cyle water consumption, based on a 10 - 30% reduction in the number of instruments. This yields water savings of approximately 1357 m3, only for the washer/disinfector processes. This is equivalent to the water consumption of 27 people. The CO2 equivalent of this water is 0.298 * 1357 = 404 kg CO2. The CO2 impact of processing the regular water to RO-water and softened water is unknown. The RO-water reduction (for a 20% instrument reduction) is 858 + (0.2 * 876) = 1033 cubic meters of RO-water. This is 16.3% of the total RO-water consumption. Therefore, 0.163 * 351 is 57.2 tons of steam are saved, not having to heat this water. The efficiency of the steam generation is unknown, but it will take about 83 m3 of gas to produce 1 ton of steam. The CO2 equivalent E of the steam is reduction is then:

$$E = 57.2 * 83 * 1.890 * \frac{1}{1000} = 9\, tons\, of\, CO2 \tag{8}$$

C Matlab Models

This section will discuss the different Matlab models step-by-step. A general description of different parts of code will be provided. The green texts in the Matlab blocks clarify specific steps and procedures. In general, the user should only change the selected Excel worksheet, the parameters par1, par2 and par_m, and the correct title corresponding to the selected worksheet.

C.1 Boxplots

The first section clears all existing variables and imports the data from the excel sheets. In general, make sure to have the excel file saved in the same folder as the Matlab. Matrices with user data are created for all three types of procedures (abdominal, laparoscopic and evaluation of abdominal with new tray contents). Lastly, a variable is assigned to the number of instruments per procedure and the number of procedures per Excel worksheet.

```
%% Preparation
clc
clear all

%% Import user data from Excel sheets
Lat_data = readcell('EXCEL DATA.xlsx','Sheet', 'Laparotomie Totaal');
Lap_data = readcell('EXCEL DATA.xlsx','Sheet', 'Laparoscopie Totaal');
Lat_eva = readcell('EXCEL DATA.xlsx','Sheet', 'Laparotomie Evaluatie');

%% Data formatting
[LatR,LatC] = size(Lat_data); %Index number of items in the sheets
[LapR,LapC] = size(Lap_data);
[EvaR,EvaC] = size(Lat_eva);
%Create matrix with user data for every sheet
Lat_user = Lat_data(2:LatR,10:LatC);
Lat_user = cell2mat(Lat_user); %Restructure cells to matrix format
Lap_user = Lap_data(2:LapR,10:LapC);
Lap_user = cell2mat(Lap_user);
Eva_user = Lat_eva(2:EvaR,10:EvaC);
Eva_user = cell2mat(Eva_user);

[LatR,LatC] = size(Lat_user); %Index number of instruments and procedures
[LapR,LapC] = size(Lap_user);
[EvaR,EvaC] = size(Eva_user);
```

The following section constructs a vector with instrument use percentages for every individual procedure. An empty array is created and a new value is added to this array for every iteration. The number is iterations is equal to the number of procedures, for every type of procedure. The loops are exactly the same for all three types, so the explanation is only given once. During one iteration, the number of instrument uses and non-uses are determined. Dividing the number of used instruments by the total number of instruments gives the use percentage for a certain procedure, which is added to the vector.

```
%% Prepare to calculate use percentage for every procedure
v = zeros(1,LatC); %Empty array to register percentages below
w = zeros(1,LapC);
t = zeros(1,EvaC);

%% Laparotomies
for i = 1:LatC %For loop to calculate the same number for every procedure
    x = Lat_user(:,i);
    one_lat = find(x==1); %Index number of used instruments
    zero_lat = find(x==0); %Unused instruments

    [C1,¬] = size (one_lat);
    [C0,¬] = size (zero_lat);
```

```
    %Calculate use percentage over valid data points
    perc_lat = C1/(C1+C0);

    v(i) = 100.*perc_lat; %construct vector with percentage per procedure
end

%% Laparoscopies (same as above)
for i = 1:LapC
    xx = Lap_user(:,i);
    one_lap = find(xx==1);
    zero_lap = find(xx==0);

    [C3,¬] = size (one_lap);
    [C2,¬] = size (zero_lap);
    perc_lap = C3/(C3+C2);
    w(i) = 100.*perc_lap;
end

%% Evaluation Laparotomies (same as above)
for i = 1:EvaC
    x = Eva_user(:,i);
    one_eva = find(x==1);
    zero_eva = find(x==0);

    [C5,¬] = size (one_eva);
    [C4,¬] = size (zero_eva);
    perc_eva = C5/(C5+C4);
    t(i) = 100.*perc_eva;
end
```

The third section calculates the mean of these vectors, including their standard deviation and the number of procedures for all three procedure types. It also imports the OR door movement data from the evaluation phase and calculates the mean and standard deviation of this data as well.

```
%% Calculate Mean, Standard deviation and number of procedures
%Laparotomies
Mv = mean(v); % Calculate mean instrument usage
SDv = std(v); % Calculate standard deviation
Nv = LatC; % Number of procedures

%Laparoscopies
Mw = mean(w);
SDw = std(w);
Nw = LapC;

%Evaluation
Me = mean(t);
SDe = std(t);
Ne = EvaC;

%% Door movements (mean and standard deviation)
Lat_Door = readcell('EXCEL DATA.xlsx','Sheet', 'Laparotomie per Procedure');
Door = Lat_Door(19:19+(EvaC-1),25:25);
Door = cell2mat(Door);

Md = mean(Door);
SDd = std(Door);
```

The final section generates the graphs, containing both the comparison of original abdominal and minimally invasive instrument use, as well as the comparison between abdominal instrument use before and after the reduction. A boxplot is chosen to be the appropriate tool in this case. The number of procedures, as shown in the graph, should be changed to the appropriate size of the data set.

```
%% Plot comparison of instrument use for laparotomies and laparoscopies
group = [ones(size(v')); 2 * ones(size(w'))];
figure
boxplot([v'; w'],group);
title('Instrument Use Percentage','FontSize',14)
ylabel('Use Percentage [%]','FontSize',14)
xlabel('Procedure Type','FontSize',14)
%Change the number of procedures below
Procedure = {'Oncological Laparotomy [n=16]';'Minimally Invasive [n=12]'};
set(gca,'xticklabel',Procedure)
ylim([10 70])

%% Plot instrument use of old and new abdominal trays
group = [ones(size(v')); 2 * ones(size(t'))];
figure
boxplot([v'; t'],group);
title('Instrument Use Percentage','FontSize',14)
ylabel('Use Percentage [%]','FontSize',14)
xlabel('Procedure Type','FontSize',14)
%Change the number of procedures below
Procedure = {'Oncological Laparotomy Old [n=16]';'Oncological Laparotomy New [n=7]'};
set(gca,'xticklabel',Procedure)
ylim([10 70])
```

C.2 Iterating Reduction

The two iterating reduction models determine the recommended new number of instruments for every minimal use percentage.

C.2.1 Excluding Removal of High-Risk Items

The first, conservative model does not allow for autonomous removal of high-risk instruments, whereas the second model does remove high risk instruments and shows the number of such removals. The first model starts, again, by importing the data from Excel. It is important to select only one Excel worksheet at a time. Otherwise, the model will only use the last selected sheet. The next step is to create a matrix with the user data of the selected procedure type and to prepare an empty array to be filled with the new number of instruments for every minimal use percentage. An interval of 5% is chosen between minimal use percentages, leading to 21 different recommendations.

```
%% Preparation
clc
clear all

%% Import user data. Only one sheet at a time!
Lat_data = readcell('EXCEL DATA.xlsx','Sheet','Laparotomie Totaal');
%Lat_data = readcell('EXCEL DATA.xlsx','Sheet','Laparoscopie Totaal');
%Lat_data = readcell('EXCEL DATA.xlsx','Sheet','Laparotomie Evaluatie');

%% Data formatting
[LatR,LatC] = size(Lat_data);
Lat_user = Lat_data(2:LatR,10:LatC);
Lat_user = cell2mat(Lat_user);

[x,y] = size(Lat_user); %number of instruments and procedures
yy = zeros(1,21); %empty array to be filled with new number of instruments
xx = [0:0.05:1]; % 5% intervals in minimal use percentage
```

The next section calculates the new recommended number of instruments for all 5% minimal use percentage intervals. This section is equal to the calculation in the Comparison.m file, which is explained in more detail below. The only difference is the removal of the fixed minimal use percentage parameter, which is replaced by the 21 iterations over different values of this parameter.

The last part ads all the recommended numbers of instruments in one vector, to plot against the minimal use percentage.

```
%% Determine recommended tray contents for every minimal use percentage
for i = 1:21
    par1 = xx(i);
Lat_name = Lat_data(2:LatR,4:5);
Lat_veto = Lat_data(2:LatR,8:8);
Lat_veto = cell2mat(Lat_veto);

Lat_NEW = Lat_name;

%% Change Parameters here!!! %%
par2 = 0.5; %Define maximum percentage of missing data points.
par_m = 7; %Data is processed according to size of the data set.
%par_m defines the size of a 'middle sized' data set. 0<par_m<100.

%% Index the use percentage per instrument
[¬,LatC]=size(Lat_user); %Define LatC as the number of procedures.

%The if—condition decides whether the data set is small (<par_m), medium
%(between par_m and 100) or large and processes the data accordingly.
if LatC ≥ 100 %for large (>100) datasets only use the last 100 datapoints

    Lat_a = Lat_user;
LatC_temp = LatC/3; %Divide data in 3 similarly sized parts
LatC_temp = round(LatC_temp);

%Multiply the second (x2) and third (x3) data part to quickly register new
%trends in instrument usage. Only works for large (>100) data sets!
Lat_a1 = Lat_a (:,1:LatC_temp);
Lat_a2 = Lat_a (:,(LatC_temp + 1):(2*LatC_temp));
Lat_a3 = Lat_a (:,(2*LatC_temp + 1):LatC);

Lat_a2 = [Lat_a2 Lat_a2];
Lat_a3 = [Lat_a3 Lat_a3 Lat_a3];
%New data set is the combination of the 3 sets.
Lat_a = [Lat_a1 Lat_a2 Lat_a3];
[¬,LatC] = size(Lat_a);

%Following 3 parts define which items should be removed based on use
%percentage, missing data and veto of high—risk items.

%Part 1 — Removal based on low use percentage
% Calculate number of uses per instrument
%Construct logical matrix with 1 = missing or used and 0 = unused
logical_Lat_used = Lat_a == 1;
id_Lat_used = logical_Lat_used≠0;
number_used_Lat = sum(id_Lat_used,2); %Sum over total number of procedures

% Same to calculate number of non—uses per instrument
logical_Lat_unused = Lat_a == 0;
id_Lat_unused = logical_Lat_unused≠0;
number_unused_Lat = sum(id_Lat_unused,2);

% Calculate fraction (used/total) and remove if < par1 value
Use_percentage_Lat = number_used_Lat./(number_used_Lat + number_unused_Lat);
Remove_Rows_Lat = Use_percentage_Lat ≤ par1; %Set value above!
Index_Remove_Rows_Lat = find(Remove_Rows_Lat); %Index rows to be deleted

%Part 2, Removal based on enough valid data points
%Create logical matrix with 1 = missing data, 0 = valid data
data_corr = Lat_a < 0;
idd = data_corr≠0;
    t = sum(idd,2); %Number of missing data points per instrument

logt = t/LatC; %Percentage of missing data points
```

```
65
66  Remove_Rows_Lat2 = logt ≤ par2; %Set value above
67  Index_Remove_Rows_Lat2 = find(Remove_Rows_Lat2);
68  %Define indices of instruments that have to be removed by part 1 and 2
69  Total_Remove_Lat = [Index_Remove_Rows_Lat; Index_Remove_Rows_Lat2];
70  Remove_Lat = sort(Total_Remove_Lat);
71  %Only remove the doubles (that fulfill condition 1 AND 2
72  [¬, ind] = unique(Remove_Lat, 'rows');
73  %Set unique values to zero, only keep instruments that have to be deleted.
74  Remove_Lat(ind,:) = [];
75
76  %part 3, third condition, veto high-risk instruments
77  %Index rows that fulfill veto condition
78  Index_Remove_Rows_Lat3 = find(Lat_veto);
79  Total_Remove_Lat2 = [Remove_Lat; Index_Remove_Rows_Lat3];
80  Remove_Lat2 = sort(Total_Remove_Lat2);
81  %Again, only remove values that fulfill all conditions (doubles)
82  [¬, ind] = unique(Remove_Lat2, 'rows');
83  Remove_Lat2(ind,:) = [];
84  %Optional: construct new list of required instruments
85  Lat_NEW(Remove_Lat2,:) = [];
86
87  %This part is the same as above, except for the division in three parts.
88  %All data is equally important for middle size data set.
89  elseif (par_m≤LatC)&&(LatC<100) %par_m is set above to determine data size
90      Lat_a = Lat_user;
91  [¬,LatC] = size(Lat_a);
92  %Part 1, 2 and 3 are the same as above
93  %part 1, Use data
94  logical_Lat_used = Lat_a == 1;
95  id_Lat_used = logical_Lat_used≠0;
96  number_used_Lat = sum(id_Lat_used,2);
97
98  logical_Lat_unused = Lat_a == 0;
99  id_Lat_unused = logical_Lat_unused≠0;
100 number_unused_Lat = sum(id_Lat_unused,2);
101
102 Use_percentage_Lat = number_used_Lat./(number_used_Lat + number_unused_Lat);
103 Remove_Rows_Lat = Use_percentage_Lat ≤ par1;
104 Index_Remove_Rows_Lat = find(Remove_Rows_Lat);
105
106 %Part2, Missing data
107 data_corr = Lat_a < 0;
108 idd = data_corr≠0;
109     t = sum(idd,2);
110 logt = t/LatC;
111 Remove_Rows_Lat2 = logt ≤ par2;
112 Index_Remove_Rows_Lat2 = find(Remove_Rows_Lat2);
113
114 Total_Remove_Lat = [Index_Remove_Rows_Lat; Index_Remove_Rows_Lat2];
115 Remove_Lat = sort(Total_Remove_Lat);
116 [¬, ind] = unique(Remove_Lat, 'rows');
117 Remove_Lat(ind,:) = [];
118
119 %part 3, veto
120 Index_Remove_Rows_Lat3 = find(Lat_veto);
121 Total_Remove_Lat2 = [Remove_Lat; Index_Remove_Rows_Lat3];
122 Remove_Lat2 = sort(Total_Remove_Lat2);
123 [¬, ind] = unique(Remove_Lat2, 'rows');
124 Remove_Lat2(ind,:) = [];
125
126 Lat_NEW(Remove_Lat2,:) = [];
127
128 %For very small dataset (< par_m), first 2 conditions are combined.
129 %Removed data only contains zeros (meaning no use and no missing data)
130 else
131     Lat_a = Lat_user;
132     Lat_b = (¬any(Lat_a,2));
133     Lat_c = find(Lat_b);
```

```
134
135 %Part3, High risk instruments are exempt from removal, same as above.
136 Index_Remove_Rows_Lat3 = find(Lat_veto);
137 Total_Remove_Lat2 = [Lat_c; Index_Remove_Rows_Lat3];
138 Remove_Lat2 = sort(Total_Remove_Lat2);
139 [¬, ind] = unique(Remove_Lat2, 'rows');
140 Remove_Lat2(ind,:) = [];
141 %Optional: construct list with new instruments
142 Lat_NEW(Remove_Lat2,:) = [];
143 end
144
145 [LatR,LatC] = size(Lat_data);
146 [testR,testC] = size(Lat_NEW);
147
148 yy(i) = testR;
149
150 end
```

The final section plots the results of the different iterations. It also marks the spot of the original number of instruments with a red cross. The title of the graph should be changed, according to the chosen procedure type.

```
1  %% Plot minimal use percentage against new recommended number of instruments
2  figure
3  plot(100.*xx,yy,'b-',0,x,'rx','LineWidth',2)
4  hold on
5  %Set to the appropriate title of the three, change n=...
6  title ({'Oncological Laparotomy [n=16]'},'FontSize',14)
7  %title ({'Laparoscopy [n=12]'},'FontSize',14)
8  %title ({'Oncological Laparotomy Evaluation [n=7]'},'FontSize',14)
9  xlabel('Minimal Use Percentage [%]')
10 ylabel('Number of Instruments')
11 ylim([0 LatR+10]);
12 legend({'Instrument Reduction Efforts','Initial Number of ...
       Instruments'},'FontSize',14)
```

C.2.2 Including Removal of High-Risk Items

The first part is almost equal to the previous model. The only difference is the creation of a vector to quantify high-risk removals. This vector will be filled with the number of high-risk removals for every minimal use percentage, before adding these numbers to the graph at the end.

```
1  %% Preparation
2  clc
3  clear all
4
5  %% Import user data. Only one sheet at a time!
6  Lat_data = readcell('EXCEL DATA.xlsx','Sheet','Laparotomie Totaal');
7  %Lat_data = readcell('EXCEL DATA.xlsx','Sheet','Laparoscopie Totaal');
8  %Lat_data = readcell('EXCEL DATA.xlsx','Sheet','Laparotomie Evaluatie');
9
10 %% Data formatting
11 [LatR,LatC] = size(Lat_data);
12 Lat_user = Lat_data(2:LatR,10:LatC);
13 Lat_user = cell2mat(Lat_user);
14
15 [x,y] = size(Lat_user);
16 Risk = zeros(1,21); %Add a vector to quantify high-risk removals
17 yy = zeros(1,21);
18 xx = [0:0.05:1];
```

The following section is very similar to the one excluding high-risk removals. Again, a detailed description can be found in the section explaining the Comparison.m file. Two minor differences

have to be disclosed. Firstly, the veto (third) part is removed from the calculation of the number of suggested removals, because this graph shows the new number of instruments including high-risk removals. Secondly, these high-risk removals are calculated separately at the end of this section. The sum of the two lines in this section adds up to the line in the previous graph.

```
%% Determine recommended tray contents, including high-risk items
for i = 1:21

   par1 = xx(i);

Lat_name = Lat_data(2:LatR,4:5);
Lat_veto = Lat_data(2:LatR,8:8);
Lat_veto = cell2mat(Lat_veto);

Lat_NEW = Lat_name;

%% Change Parameters here!!! %%
par2 = 0.5; %Define maximum percentage of missing data points.
par_m = 7; %Data is processed according to size of the data set.
%par_m defines the size of a 'middle sized' data set. 0<par_m<100.

%% Index the use percentage per instrument
[¬,LatC]=size(Lat_user); %Define LatC as the number of procedures.

%The if-condition decides whether the data set is small (<par_m), medium
%(between par_m and 100) or large and processes the data accordingly.
if LatC ≥ 100 %for large (>100) datasets only use the last 100 datapoints

    Lat_a = Lat_user;
LatC_temp = LatC/3; %Divide data in 3 similarly sized parts
LatC_temp = round(LatC_temp);

%Multiply the second (x2) and third (x3) data part to quickly register new
%trends in instrument usage. Only works for large (>100) data sets!
Lat_a1 = Lat_a (:,1:LatC_temp);
Lat_a2 = Lat_a (:,(LatC_temp + 1):(2*LatC_temp));
Lat_a3 = Lat_a (:,(2*LatC_temp + 1):LatC);

Lat_a2 = [Lat_a2 Lat_a2];
Lat_a3 = [Lat_a3 Lat_a3 Lat_a3];
%New data set is the combination of the 3 sets.
Lat_a = [Lat_a1 Lat_a2 Lat_a3];
[¬,LatC] = size(Lat_a);

%Following 2 parts define which items should be removed based on use
%percentage, missing data and veto of high-risk items.

%Part 1 - Removal based on low use percentage
% Calculate number of uses per instrument
% Construct logical matrix with 1 = missing or used and 0 = unused
logical_Lat_used = Lat_a == 1;
id_Lat_used = logical_Lat_used≠0;
number_used_Lat = sum(id_Lat_used,2); %Sum over total number of procedures

% Same to calculate number of non-uses per instrument
logical_Lat_unused = Lat_a == 0;
id_Lat_unused = logical_Lat_unused≠0;
number_unused_Lat = sum(id_Lat_unused,2);

% Calculate fraction (used/total) and remove if < par1 value
Use_percentage_Lat = number_used_Lat./(number_used_Lat + number_unused_Lat);
Remove_Rows_Lat = Use_percentage_Lat ≤ par1; %Set value above!
Index_Remove_Rows_Lat = find(Remove_Rows_Lat); %Index rows to be deleted

%Part 2, Removal based on enough valid data points
%Create logical matrix with 1 = missing data, 0 = valid data
data_corr = Lat_a < 0;
```

```
idd = data_corr≠0;
    t = sum(idd,2); %Number of missing data points per instrument

logt = t/LatC; %Percentage of missing data points

Remove_Rows_Lat2 = logt ≤ par2; %Set value above
Index_Remove_Rows_Lat2 = find(Remove_Rows_Lat2);
%Define indices of instruments that have to be removed by part 1 and 2
Total_Remove_Lat = [Index_Remove_Rows_Lat; Index_Remove_Rows_Lat2];
Remove_Lat = sort(Total_Remove_Lat);
%Only remove the doubles (that fulfill condition 1 AND 2
[¬, ind] = unique(Remove_Lat, 'rows');
%Set unique values to zero, only keep instruments that have to be deleted.
Remove_Lat(ind,:) = [];

Lat_NEW(Remove_Lat,:) = [];

%This part is the same as above, except for the division in three parts.
%All data is equally important for middle size data set.
elseif (par_m≤LatC)&&(LatC<100) %par_m is set above to determine data size
    Lat_a = Lat_user;
[¬,LatC] = size(Lat_a);
%Part 1 and 2 are the same as above
%part 1, Use data
logical_Lat_used = Lat_a == 1;
id_Lat_used = logical_Lat_used≠0;
number_used_Lat = sum(id_Lat_used,2);

logical_Lat_unused = Lat_a == 0;
id_Lat_unused = logical_Lat_unused≠0;
number_unused_Lat = sum(id_Lat_unused,2);

Use_percentage_Lat = number_used_Lat./(number_used_Lat + number_unused_Lat);
Remove_Rows_Lat = Use_percentage_Lat ≤ par1;
Index_Remove_Rows_Lat = find(Remove_Rows_Lat);

%Part2, Missing data
data_corr = Lat_a < 0;
idd = data_corr≠0;
    t = sum(idd,2);
logt = t/LatC;
Remove_Rows_Lat2 = logt ≤ par2;
Index_Remove_Rows_Lat2 = find(Remove_Rows_Lat2);

Total_Remove_Lat = [Index_Remove_Rows_Lat; Index_Remove_Rows_Lat2];
Remove_Lat = sort(Total_Remove_Lat);
[¬, ind] = unique(Remove_Lat, 'rows');
Remove_Lat(ind,:) = [];

Lat_NEW(Remove_Lat,:) = [];

else
    Lat_a = Lat_user;
    Lat_b = (¬any(Lat_a,2));
    Lat_c = find(Lat_b);

    Lat_NEW(Lat_c,:) = [];
end

[LatR,LatC] = size(Lat_data);
[testR,testC] = size(Lat_NEW);
yy(i) = testR;

%Count the number of high—risk removals
Veto = find(¬Lat_veto); %Vector with high—risk instruments
Combined = [Remove_Lat; Veto]; %Add to vector with suggested removals
%Index size of combined removal suggestions and high—risk items
[aa,¬] = size(Combined);
Combined_unique = unique(Combined);
```

```
[bb,¬] = size(Combined_unique); %size of unique values in the vector

Highrisk_Instr = aa - bb; %difference is the number of high-risk removals
Risk(i) = Highrisk_Instr; %Risk vector contains this number per iteration
end
```

The final section shows the creation of the iterative reduction graph, separately exhibiting the suggested high-risk removals. The different vectors (yy and Risk) are plotted in the same figure. Again, the title has to be changed according to the specific Excel worksheet.

```
%% Plot total removal suggestion and high-risk part
figure
plot(0,x,'rx',100.*xx,yy,'b-',100.*xx,Risk,'g--','LineWidth',2)
hold on
%Set to the appropriate title
title ({'Oncological Laparotomy [n=16]'},'FontSize',14)%Select the right title
%title ({'Laparoscopy [n=12]'},'FontSize',14)
%title ({'Oncological Laparotomy Evaluation [n=7]'},'FontSize',14)
xlabel('Minimal Use Percentage [%]')
ylabel('Number of Instruments')
ylim([0 LatR+10]);
legend({'Initial Number of Instruments','Instrument Reduction Efforts','Number of ...
    High Risk Removals'},'FontSize',14)
```

C.3 Comparison.m

The fourth and last model compares the tray recommendations based on different minimal use percentages to the suggested tray compositions based on the expert opinions. It also compares the suggestions of medical specialists and OR-assistants themselves. Finally, it also performs a second risk analysis, to determine the possibility of missing an instrument during surgery in case the new tray composition is based on one of the three reduction methods. As usual, the first part clears any existing variables, imports the data from the Excel file and assigns variables to the user data, risk information and instrument names. The minimal use percentage (par1), maximum amount of missing data (par2) and definition of a middle-sized data set (par_m) can be altered in this section as well.

```
%% Preparation - Delete variables before running script
clc
clear all
%% Import user data from Excel
%Choose one of the following excel sheets, based on the type of procedure
Lat_data = readcell('EXCEL DATA.xlsx','Sheet', 'Laparotomie Totaal');
%Lat_data = readcell('EXCEL DATA.xlsx','Sheet', 'Laparoscopie Totaal');

%% Data formatting
%Index the number of instruments and number of procedures
[LatR,LatC] = size(Lat_data);

Lat_user = Lat_data(2:LatR,10:LatC); %Create matrix with user data
Lat_user = cell2mat(Lat_user); %Change the 'cell' structure to matrix form
Lat_name = Lat_data(2:LatR,3:4); %Isolate Instrument Names
Lat_veto = Lat_data(2:LatR,8:8); %Data concerning high-risk items
Lat_veto = cell2mat(Lat_veto);
Lat_NEW = Lat_name; %Prepare to create new list of instruments at the end

%% Change Parameters here!!! %%
par1 = 0.10; %Define minimal use percentage here, instruments
%used less than this value will be removed from the tray
par2 = 0.5; %Same for missing data points.
par_m = 7; %Data is processed according to size of the data set.
%par_m defines the size of a 'middle sized' data set. 0<par_m<100.
```

The next sections will create a new composition of tray contents, based on the chosen parameters and the size of the data set. A very large data-set is considered first. The LUMC performs roughly 100 oncological laparotomies per year, which is why a large data-set contains data of more than 100 procedures. The code of the next segment starts by checking whether the data set contains over 100 procedures. Otherwise, the if-condition moves further down to check for a middle sized data-set. Large data-sets are divided in three equally large parts, multiplying the oldest part by 1, the middle part by 2 and the most recent part by 3. This will ensure early detection of trends and changes in instrument use. An autonomous tray optimization system should not wait a year before such trends are detected. A new data-set is created by adding the multiplied parts together in a new variable Lat_a.

```
%% Instrumenten indexeren die (regelmatig) gebruikt worden
[¬,LatC]=size(Lat_user); %Define LatC as the number of procedures.
%The if—condition decides whether the data set is small (<par_m), medium
%(between par_m and 100) or large and processes the data accordingly.
if LatC ≥ 100 %for large (>100) datasets only use the last 100 datapoints

    Lat_a = Lat_user;
LatC_temp = LatC/3; %Divide data in 3 similarly sized parts
LatC_temp = round(LatC_temp);

%Multiply the second (x2) and third (x3) data part to quickly register new
%trends in instrument usage. Only works for large (>100) data sets!
Lat_a1 = Lat_a (:,1:LatC_temp);
Lat_a2 = Lat_a (:,(LatC_temp + 1):(2*LatC_temp));
Lat_a3 = Lat_a (:,(2*LatC_temp + 1):LatC);

Lat_a2 = [Lat_a2 Lat_a2];
Lat_a3 = [Lat_a3 Lat_a3 Lat_a3];
%New data set is the combination of the 3 sets.
Lat_a = [Lat_a1 Lat_a2 Lat_a3];
[¬,LatC] = size(Lat_a);
```

The model tries to label instruments suitable for removal, based on three criteria: use percentage of instruments, a maximum amount of missing data and risk data of individual instruments. This section considers the first criterion. The number of instrument uses and non-uses are determined. Next, the number of uses is divided by the summed number of uses and non-uses to determine the use percentage. Items with a use percentage below the previously set minimal use parameter (par1) are indexed for removal.

```
%Part 1 — Removal based on low use percentage
% Calculate number of uses per instrument
%Construct logical matrix with 1 = missing or used and 0 = unused
logical_Lat_used = Lat_a == 1;
id_Lat_used = logical_Lat_used≠0;
number_used_Lat = sum(id_Lat_used,2); %Sum over total number of procedures

% Same to calculate number of non—uses per instrument
logical_Lat_unused = Lat_a == 0;
id_Lat_unused = logical_Lat_unused≠0;
number_unused_Lat = sum(id_Lat_unused,2);

% Calculate fraction (used/total) and remove if < par1 value
Use_percentage_Lat = number_used_Lat./(number_used_Lat + number_unused_Lat);
Remove_Rows_Lat = Use_percentage_Lat ≤ par1; %Set value above!
Index_Remove_Rows_Lat = find(Remove_Rows_Lat); %Index rows to be deleted
```

Similarly, the number of missing data points is determined and compared to the previously set maximum percentage of missing data points. If the missing data percentage is below the set value par2, the item is considered safe to be removed. Missing data percentages larger than par2 should be exempt from removal, as the missing data might badly influence use and non-use percentages. The instruments that are indexed for removal by both parameters are added to a vector and sorted.

Only the instruments that fulfill both conditions (doubles) are indexed for removal, by deleting the unique (single) values.

```
%Part 2, Removal based on enough valid data points
%Create logical matrix with 1 = missing data, 0 = valid data
data_corr = Lat_a < 0;
idd = data_corr≠0;
    t = sum(idd,2); %Number of missing data points per instrument

logt = t/LatC; %Percentage of missing data points

Remove_Rows_Lat2 = logt ≤ par2; %Set value above
Index_Remove_Rows_Lat2 = find(Remove_Rows_Lat2);
%Define indices of instruments that have to be removed by part 1 and 2
Total_Remove_Lat = [Index_Remove_Rows_Lat; Index_Remove_Rows_Lat2];
Remove_Lat = sort(Total_Remove_Lat);
%Only remove the doubles (that fulfill condition 1 AND 2
[¬, ind] = unique(Remove_Lat, 'rows');
%Set unique values to zero, only keep instruments that have to be deleted.
Remove_Lat(ind,:) = [];
```

The final criterion for large data-sets is based on the exemption of autonomous deletion of high-risk items. The model may only remove low-risk items. High-risk instruments would have to be discussed with the medical specialists and OR-assistants. The model indexes low-risk items, which are suitable for removal), adds these indices to the vector of suggested removals and, once again, deletes single values to keep only the items that fulfill all three criteria. The new instrument list Lat_NEW is created by removing the indexed items.

```
%part 3, third condition, veto high—risk instruments
%Index rows that fulfill veto condition
Index_Remove_Rows_Lat3 = find(Lat_veto);
Total_Remove_Lat2 = [Remove_Lat; Index_Remove_Rows_Lat3];
Remove_Lat2 = sort(Total_Remove_Lat2);
%Again, only remove values that fulfill all conditions (doubles)
[¬, ind] = unique(Remove_Lat2, 'rows');
Remove_Lat2(ind,:) = [];
%Optional: construct new list of required instruments
Lat_NEW(Remove_Lat2,:) = [];
```

The next section describes exactly the same procedure for middle-sized data sets. In this case, all data is equally important and the multiplication procedure for early trend detection is not performed. The rest of the code is equal to the previous section and will therefore not be explained step-by-step.

```
elseif (par_m≤LatC)&&(LatC<100) %par_m is set above to determine data size
    Lat_a = Lat_user;
[¬,LatC] = size(Lat_a);
%Part 1, 2 and 3 are the same as above
%part 1, Use data
logical_Lat_used = Lat_a == 1;
id_Lat_used = logical_Lat_used≠0;
number_used_Lat = sum(id_Lat_used,2);

logical_Lat_unused = Lat_a == 0;
id_Lat_unused = logical_Lat_unused≠0;
number_unused_Lat = sum(id_Lat_unused,2);

Use_percentage_Lat = number_used_Lat./(number_used_Lat + number_unused_Lat);
Remove_Rows_Lat = Use_percentage_Lat ≤ par1;
Index_Remove_Rows_Lat = find(Remove_Rows_Lat);

%Part2, Missing data
data_corr = Lat_a < 0;
```

```
idd = data_corr≠0;
    t = sum(idd,2);
logt = t/LatC;
Remove_Rows_Lat2 = logt ≤ par2;
Index_Remove_Rows_Lat2 = find(Remove_Rows_Lat2);

Total_Remove_Lat = [Index_Remove_Rows_Lat; Index_Remove_Rows_Lat2];
Remove_Lat = sort(Total_Remove_Lat);
[¬, ind] = unique(Remove_Lat, 'rows');
Remove_Lat(ind,:) = [];

%part 3, veto
Index_Remove_Rows_Lat3 = find(Lat_veto);
Total_Remove_Lat2 = [Remove_Lat; Index_Remove_Rows_Lat3];
Remove_Lat2 = sort(Total_Remove_Lat2);
[¬, ind] = unique(Remove_Lat2, 'rows');
Remove_Lat2(ind,:) = [];

Lat_NEW(Remove_Lat2,:) = [];
```

Finally, for small data-sets (smaller than par_m), the first two criteria are combined. As small data-sets have less margin for error, not a single missing data point or non-use is allowed. Only instruments with a complete row of zeros (non-uses) are considered for removal. Exemption of high-risk items remains unchanged. Lastly, the variables LatR and LatC are reset to the number of instruments and procedures, respectively.

```
else
    Lat_a = Lat_user;
    Lat_b = (¬any(Lat_a,2));
    Lat_c = find(Lat_b);

%Part3, High risk instruments are exempt from removal, same as above.
Index_Remove_Rows_Lat3 = find(Lat_veto);
Total_Remove_Lat2 = [Lat_c; Index_Remove_Rows_Lat3];
Remove_Lat2 = sort(Total_Remove_Lat2);
[¬, ind] = unique(Remove_Lat2, 'rows');
Remove_Lat2(ind,:) = [];
%Optional: construct list with new instruments
Lat_NEW(Remove_Lat2,:) = [];
end

[LatR,LatC] = size(Lat_user);
```

Now that the new tray contents have been determined, the model will continue to compare the different methodologies. Therefore, a list of tray recommendations, with a 1 to keep on the tray and a 0 to remove from the tray, has to be created for all three methods. The lists for specialist and OR-assistant opinions are derived directly from the Excel worksheet and changed to matrix format.

```
%% Comparison between subjective and objective recommendations
%Construct 3 lists with 1='on tray' & 0='not on tray', for user data, medical ...
    specialist opinion and OR—assistant opinion.
Instr_Data = ones(LatR,1);
Instr_Data(Remove_Lat2) = 0;
%Remove_Lat2 contains items that are recommended to be removed

Instr_Spec = Lat_data(2:(LatR+1),6);
Instr_Spec = cell2mat(Instr_Spec);
Instr_OKass = Lat_data(2:(LatR+1),7);
Instr_OKass = cell2mat(Instr_OKass);
```

The recommendation based on the user data (according to the chosen parameters) will be compared to the specialists opinion first. For every instrument, the model checks whether both recommendations suggest a '1' (on the tray), a '0' (not on the tray), or whether they disagree. The

values in each vector are summed to find the absolute number of incidences for all 4 possibilities. These will be used to create the pie chart later on. An intermediate section creates a list of the unique recommendations for both methods. These lists will be considered in the next Appendix to specify the reasons for these differences, based on the possible reasons as described in the 'Discussion' section.

```
%This section will describe similarities and differences between the
%different reduction methods. First between data and specialist opinion.
both_SD = zeros(LatR,1); %create empty vectors
none_SD = zeros(LatR,1);
noton1_SD = zeros(LatR,1);
noton2_SD = zeros(LatR,1);
%This for loop indexes the items that are recommended on and off the tray
%by both, and the items that are recommended by only 1 method.
for i = 1:LatR
    if Instr_Data(i) == Instr_Spec(i) && Instr_Data(i) == 1
        both_SD(i) = 1;

    elseif Instr_Data(i) == Instr_Spec(i) && Instr_Data(i) == 0
        none_SD(i) = 1;

    elseif Instr_Data(i) ≠ Instr_Spec(i) && Instr_Data(i) == 1
        noton1_SD(i) = 1;

    elseif Instr_Data(i) ≠ Instr_Spec(i) && Instr_Data(i) == 0
        noton2_SD(i) = 1;

    end
end

%% Optional — Construct list of unique recommendations per method
Lat_name_specd = Lat_name;
Lat_name_datas = Lat_name;

Lat_name_specd(¬noton2_SD,:) = [];
Lat_name_datas(¬noton1_SD,:) = [];

%% Sum the indexed items to find absolute value.
both_SD = sum(both_SD);
none_SD = sum(none_SD);
NotS_SD = sum(noton1_SD);
NotD_SD = sum(noton2_SD);
%a 0 value will cause errors in the pie chart below
if both_SD == 0
    both_SD = 0.001;
end
if none_SD == 0
    none_SD = 0.001;
end
if NotS_SD == 0
    NotS_SD = 0.001;
end
if NotD_SD == 0
    NotD_SD = 0.001;
end
```

Exactly the same procedure is repeated for the comparison between the objective user data and OR-assistants, as well as the comparison between the specialists and the OR-assistants. Finally, the total number of recommended instruments is also determined for every reduction method. These numbers will be used to create the bar graphs below.

```
%Exactly the same for comparison between OR—assistants and data.
both_OD = zeros(LatR,1);
none_OD = zeros(LatR,1);
noton1_OD = zeros(LatR,1);
```

```
noton2_OD = zeros(LatR,1);

for i = 1:LatR
    if Instr_Data(i) == Instr_OKass(i) && Instr_Data(i) == 1
        both_OD(i) = 1;

    elseif Instr_Data(i) == Instr_OKass(i) && Instr_Data(i) == 0
        none_OD(i) = 1;

    elseif Instr_Data(i) ≠ Instr_OKass(i) && Instr_Data(i) == 1
        noton1_OD(i) = 1;

    elseif Instr_Data(i) ≠ Instr_OKass(i) && Instr_Data(i) == 0
        noton2_OD(i) = 1;

    end
end

%% Optional — Construct list of unique recommendations per method
Lat_name_ORassd = Lat_name;
Lat_name_datao = Lat_name;

Lat_name_ORassd(¬noton2_OD,:) = [];
Lat_name_datao(¬noton1_OD,:) = [];

%%
both_OD = sum(both_OD);
none_OD = sum(none_OD);
NotO_OD = sum(noton1_OD);
NotD_OD = sum(noton2_OD);

if both_OD == 0
    both_OD = 0.001;
end
if none_OD == 0
    none_OD = 0.001;
end
if NotO_OD == 0
    NotO_OD = 0.001;
end
if NotD_OD == 0
    NotD_OD = 0.001;
end

%Exactly the same for comparison between OR—assistants and specialists
both_SO = zeros(LatR,1);
none_SO = zeros(LatR,1);
noton1_SO = zeros(LatR,1);
noton2_SO = zeros(LatR,1);

for i = 1:LatR
    if Instr_Spec(i) == Instr_OKass(i) && Instr_Spec(i) == 1
        both_SO(i) = 1;

    elseif Instr_Spec(i) == Instr_OKass(i) && Instr_Spec(i) == 0
        none_SO(i) = 1;

    elseif Instr_Spec(i) ≠ Instr_OKass(i) && Instr_Spec(i) == 1
        noton2_SO(i) = 1;

    elseif Instr_Spec(i) ≠ Instr_OKass(i) && Instr_Spec(i) == 0
        noton1_SO(i) = 1;

    end
end

%% Optional — Construct list of unique recommendations per method
Lat_name_speco = Lat_name;
Lat_name_ORasss = Lat_name;
```

```
74
75  Lat_name_speco(¬noton2_SO,:) = [];
76  Lat_name_ORasss(¬noton1_SO,:) = [];
77
78  %%
79  both_SO = sum(both_SO);
80  none_SO = sum(none_SO);
81  NotS_SO = sum(noton1_SO);
82  NotO_SO = sum(noton2_SO);
83
84  if both_SO == 0
85      both_SO = 0.001;
86  end
87  if none_SO == 0
88      none_SO = 0.001;
89  end
90  if NotS_SO == 0
91      NotS_SO = 0.001;
92  end
93  if NotO_SO == 0
94      NotO_SO = 0.001;
95  end
96
97  %Also sum the new number of instruments according to every recommendation
98  Tot_Data = sum(Instr_Data);
99  Tot_Spec = sum(Instr_Spec);
100 Tot_OKass = sum(Instr_OKass);
```

A short optional section allows for the creation of new instrument lists, based on the specialists and OR-assistants opinions.

```
1  %% Optional: create new instrument list based on expert recommendations
2  Lat_NEW_Spec = Lat_name;
3  Remove_Spec = ¬Instr_Spec; %Index rows to be deleted
4  Lat_NEW_Spec(Remove_Spec,:) = []; % Remove indexed items
5
6  Lat_NEW_OKass = Lat_name; %Same for OR-assistants
7  Remove_OKass = ¬Instr_OKass;
8  Lat_NEW_OKass(Remove_OKass,:) = [];
```

Three different graphs are created for all three comparisons. The titles should be changed according to the chosen procedure type. A pie chart shows the overlap and differences between the compared recommendations. A bar graph shows the suggested number of instruments for every recommendation.

```
1  %% Plot results of Data vs. Specialists
2  pie_SD = [both_SD, none_SD, NotS_SD, NotD_SD]; %Variables for pie chart
3  figure
4  %Change title according to the chosen procedure type (and excel sheet)
5  sgtitle({'Comparison Oncological Laparotomies - Objective Data vs. ...
       Specialists','[n=16] Procedures & Minimal Use Percentage is 0%'})
6  %sgtitle({'Comparison Laparoscopies - Objective Data vs. Specialists','[n=12] ...
       Procedures & Minimal Use Percentage is 10%'})
7
8  subplot(1,2,1); %first plot is the pie chart
9  pie(pie_SD)
10 legend({'Recommended on Tray by Both', 'Not Recommended on Tray by Both', 'Only ...
       recommended on tray by Data','Only recommended on tray by ...
       Specialists'},'Location','south','Orientation','vertical');
11
12 subplot(1,2,2); %second plot is the bar graph
13 x = [1,2,3];
14 y = [Tot_Spec, LatR-Tot_Spec; 0,0; Tot_Data, LatR-Tot_Data;];
15 name_SD = {'Specialists';'';'Data'};
16 h = bar(x,y,'stacked');
17 set(h,{'FaceColor'},{'r';'w'});
```

```
set(gca,'xticklabel',name_SD)
ylabel('New number of Instruments [as part of old number]')
ylim([0 (LatR+10)])

%% Plot results of Data vs. OR-assistant (same as above)
pie_OD = [both_OD, none_OD, NotO_OD, NotD_OD];
figure
sgtitle({'Comparison Oncological Laparotomies - Objective Data vs. ...
    OR-assistant','[n=16] Procedures & Minimal Use Percentage is 10%'})
%sgtitle({'Comparison Laparoscopies - Objective Data vs. OR-assistant','[n=12] ...
    Procedures & Minimal Use Percentage is 10%'})
subplot(1,2,1);
pie(pie_OD)
legend({'Recommended on Tray by Both', 'Not Recommended on Tray by Both', 'Only ...
    recommended on tray by Data','Only recommended on tray by ...
    OR-assistant'},'Location','south','Orientation','vertical');

subplot(1,2,2);
x = [1,2,3];
y = [Tot_OKass, LatR-Tot_OKass; 0, 0; Tot_Data, LatR-Tot_Data];
name_OD = {'OR-Assistant';'';'Data'};
hh = bar(x,y,'stacked');
set(hh,{'FaceColor'},{'r';'w'});
set(gca,'xticklabel',name_OD)
ylabel('New number of Instruments [as part of old number]')
ylim([0 (LatR+10)])

%% Plot results of Specialists vs. OR-assistants (same as above)
pie_SO = [both_SO, none_SO, NotS_SO, NotO_SO];
figure
sgtitle('Comparison Oncological Laparotomies - Specialists vs. OR-assistant')
%sgtitle('Comparison Laparoscopies - Specialists vs. OR-assistant')

subplot(1,2,1);
pie(pie_SO)
legend({'Recommended on Tray by Both', 'Not Recommended on Tray by Both','Only ...
    recommended on tray by OR-assistant','Only recommended on tray by ...
    Specialist'},'Location','south','Orientation','vertical');

subplot(1,2,2);
x = [1,2,3];
y = [Tot_Spec, LatR-Tot_Spec; 0, 0; Tot_OKass, LatR-Tot_OKass];
name_SO = {'Specialist';'';'OR-Assistant'};
hhh = bar(x,y,'stacked');
set(hhh,{'FaceColor'},{'r';'w'});
set(gca,'xticklabel',name_SO)
ylabel('New number of Instruments [as part of old number]')
ylim([0 (LatR+10)])
```

The last part of the model calculates the values needed for the second risk analysis. It starts by importing the user and risk data of the new tray contents during the evaluation phase. This data is used to check, hypothetically, how many low-risk and high-risk items would have been missed during the evaluation phase if the new tray contents were based on one of the reduction methodologies, instead of the combination of the three. A new, theoretical tray composition is created, and the inverse of the zeros (removed items) are multiplied with the user data from the evaluation phase to find the number of misses. These indexed misses are multiplied with the risk data to find the high-risk part of these misses. Subtracting these two numbers yields the number of low-risk misses. This process is repeated for all three methodologies. Finally, the absolute number of recommended high-risk and low-risk instrument removals is calculated. This information is incorporated in the numeric tables of the second risk analysis.

```
%% Evaluation - Risk analysis 2
Eva_Data = readcell('EXCEL DATA.xlsx','Sheet','Laparotomie Risico');
%construct matrix with user data during evaluation.
Eva_Use = Eva_Data(2:LatR+1,3:3);
```

```
Eva_Use = cell2mat(Eva_Use);
%create array with 1=high-risk, 0=low-risk
Eva_HRisk = Eva_Data(2:LatR+1,4:4);
Eva_HRisk = cell2mat(Eva_HRisk);

New_Tray = ones(LatR,1);
New_Tray(Remove_Lat) = 0; %Set to 0 for removed items (no risk veto!)
%multiply by inverse of new tray contents, to index theoretical misses.
Miss_Total_Data = Eva_Use .* ~New_Tray;
%check for all misses which ones are high-risk items.
Miss_High = Miss_Total_Data .* Eva_HRisk;

%sum values of the arrays to find absolute number of misses.
Miss_Total_Data = sum(Miss_Total_Data);
Miss_High = sum(Miss_High);
Miss_Low = Miss_Total_Data - Miss_High;

%Do the same for the recommended subjective compositions
Miss_Total_Spec = Eva_Use .* ~Instr_Spec;
Miss_Total_ORass = Eva_Use .* ~Instr_OKass;
Miss_High_Spec = Miss_Total_Spec .* Eva_HRisk;
Miss_High_ORass = Miss_Total_ORass .* Eva_HRisk;

Miss_Total_Spec = sum(Miss_Total_Spec);
Miss_Total_ORass = sum(Miss_Total_ORass);
Miss_High_Spec = sum(Miss_High_Spec);
Miss_High_ORass = sum(Miss_High_ORass);
Miss_Low_Spec = Miss_Total_Spec - Miss_High_Spec;
Miss_Low_ORass = Miss_Total_ORass - Miss_High_ORass;

%Calculate number of suggested High-Risk and Low-Risk Item Removals
%for subjective recommendations. Needed for evaluation risk table
Removals_Spec_T = sum(~Instr_Spec);
Removals_Spec_H = sum(~Instr_Spec .* Eva_HRisk);
Removals_Spec_L = Removals_Spec_T - Removals_Spec_H;

Removals_ORass_T = sum(~Instr_OKass);
Removals_ORass_H = sum(~Instr_OKass .* Eva_HRisk);
Removals_ORass_L = Removals_ORass_T - Removals_ORass_H;
```

D Excel Files Differences Between Recommendations

This section explains the differences between the recommended tray compositions, for three different examples. The reasons in the right column of the presented figures correspond to the reasons in the 'Discussion' section. Fig. 21 compares the recommendations of the medical specialists to the suggestion of the OR-assistants. Fig. 22 and 23 compare the specialists suggestions to the recommendation based on the user data for minimal use percentages of 0% and 10%, respectively.

Only recommended by OR-assistant		Reason
'BA03'	'KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb'	11,12
'BA04'	'KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb'	11,12
'BA13'	'KLEM ARTERIE vlg PEAN 14 cm geb'	13
'BA14'	'KLEM ARTERIE vlg PEAN 14 cm geb'	13
'BA15'	'KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb'	15
'BA16'	'KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb'	15
'BA37'	'HAAK WOND vlg KOCHER 21 cm blad 20 mm x 12 mm'	10
'BA38'	'HAAK WOND vlg KOCHER 21 cm blad 20 mm x 12 mm'	10
'BA53'	'SCHAAR PREPAREER vlg STILLE 15 cm geb'	16
'BA55'	'SPERDER WOND vlg WEITLANER 24 cm 3-4 t stomp'	11,12
'BA58'	'NAALD DRAIN nr 14'	11
'BA60'	'MESHEFT nr 7'	13
'GY01'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb'	13
'GY02'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb'	13
'GY05'	'KLEM ARTERIE vlg ROCHESTER-OCHSNER 20 cm geb'	15
'GY06'	'KLEM ARTERIE vlg ROCHESTER-OCHSNER 20 cm geb'	15
'GY09'	'KLEM ARTERIE vlg ROCHESTER-OCHSNER 18 cm geb'	15
'GY10'	'KLEM ARTERIE vlg ROCHESTER-OCHSNER 18 cm geb'	15
'GY11'	'NAALDVOERDER vlg WERTHEIM 24 cm'	11
'GY12'	'TANG OVARIUM vlg DOYEN 18,5 cm'	14
'GY21'	'TANG KOREN vlg MAIER 26 cm met cremaillere'	14
'GY32'	'SCHAAR PREPAREER vlg NELSON-METZENB 23 cm geb'	8
'ON10'	'TANG PAK WEEFSEL vlg DUVAL 23 cm'	12
'ON11'	'TANG PAK WEEFSEL vlg DUVAL 23 cm'	12
'ON14'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb'	13
'ON15'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb'	13
'ON16'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb spits'	13
'ON17'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb spits'	13
'ON34'	'PINCET BIPOLAIR BAJONET 25 cm'	13
'ON41'	'SPECULUM vlg DOYEN 24 cm 35 x 120 mm'	12
Only recommended by Specialist		Reason
'BA09'	'TANG PAK WEEFSEL vlg ALLIS 15 cm'	3
'BA10'	'TANG PAK WEEFSEL vlg ALLIS 15 cm'	3
'BA21'	'KLEM PREPAREER vlg HEISS 19,5 cm geb'	2
'BA22'	'KLEM PREPAREER vlg HEISS 19,5 cm geb'	2
'BA43'	'PINCET ATRAUM vlg DE BAKEY 20 cm 2,8 mm'	1
'GY34'	'SCHAAR PREPAREER vlg METZENBAUM 25 cm geb'	7
'ON26'	'HAAK WOND vlg KOCHER 21 cm blad 20 mm x 12 mm'	9
'ON27'	'HAAK WOND vlg KOCHER 21 cm blad 20 mm x 12 mm'	9

Figure 21: Reasons for Unique Recommendations Between Methods - Specialists vs. OR-assistants

A	B	C
Only recommended by data 0%		Reason
'BA03'	'KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb'	19
'BA04'	'KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb'	19
'BA13'	'KLEM ARTERIE vlg PEAN 14 cm geb'	19
'BA14'	'KLEM ARTERIE vlg PEAN 14 cm geb'	19
'BA15'	'KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb'	21
'BA16'	'KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb'	21
'BA17'	'KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb'	21
'BA31'	'HAAK WOND vlg SAUERBRUCH 46 x 16 mm'	21
'BA37'	'HAAK WOND vlg KOCHER 21 cm blad 20 mm x 12 mm'	9
'BA53'	'SCHAAR PREPAREER vlg STILLE 15 cm geb'	21
'BA56'	'HAAK WOND vlg SENN-MILLER 16,5 cm 3 tands scherp 18 x 6 mm'	19
'BA60'	'MESHEFT nr 7'	19
'BA61'	'MAT MAGNEET tbv naalden'	19
'GY01'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb'	19
'GY02'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb'	19
'GY05'	'KLEM ARTERIE vlg ROCHESTER-OCHSNER 20 cm geb'	19
'GY09'	'KLEM ARTERIE vlg ROCHESTER-OCHSNER 18 cm geb'	19
'GY10'	'KLEM ARTERIE vlg ROCHESTER-OCHSNER 18 cm geb'	19
'GY12'	'TANG OVARIUM vlg DOYEN 18,5 cm'	21
'GY32'	'SCHAAR PREPAREER vlg NELSON-METZENB 23 cm geb'	18
'GY35'	'SCHAAR PREPAREER vlg METZENBAUM 20 cm geb'	18
'ON04'	'TANG PAK WEEFSEL vlg ALLIS 19 cm'	18, 20
'ON05'	'TANG PAK WEEFSEL vlg ALLIS 19 cm'	18, 20
'ON16'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb spits'	9
'ON17'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb spits'	9
'ON34'	'PINCET BIPOLAIR BAJONET 25 cm'	19
'ON41'	'SPECULUM vlg DOYEN 24 cm 35 x 120 mm'	18
Only recommended by specialists 0%		Reason
'GY26'	'SPECULUM vlg DOYEN 24 cm 90 x 35 mm'	7
'GY33'	'SCHAAR PREPAREER vlg ZEPPELIN 23 cm geb'	6
'ON09'	'TANG PAK WEEFSEL vlg BABCOCK 24 cm'	10

Figure 22: Reasons for Unique Recommendations Between Methods - Specialists vs. 0% Data

Only recommended by data 10%		Reason
'BA03'	'KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb'	19
'BA04'	'KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb'	19
'BA13'	'KLEM ARTERIE vlg PEAN 14 cm geb'	19
'BA14'	'KLEM ARTERIE vlg PEAN 14 cm geb'	19
'BA15'	'KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb'	21
'BA16'	'KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb'	21
'BA37'	'HAAK WOND vlg KOCHER 21 cm blad 20 mm x 12 mm'	9
'BA53'	'SCHAAR PREPAREER vlg STILLE 15 cm geb'	21
'GY01'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb'	19
'GY02'	'KLEM ARTERIE vlg CRAFOORD 24,5 cm geb'	19
'GY32'	'SCHAAR PREPAREER vlg NELSON-METZENB 23 cm geb'	18
'GY35'	'SCHAAR PREPAREER vlg METZENBAUM 20 cm geb'	18
'ON04'	'TANG PAK WEEFSEL vlg ALLIS 19 cm'	18, 20
'ON05'	'TANG PAK WEEFSEL vlg ALLIS 19 cm'	18, 20
'ON34'	'PINCET BIPOLAIR BAJONET 25 cm'	19
Only recommended by specialists 10%		
'BA30'	'LEPEL KROP vlg KOCHER'	1
'BA34'	'HAAK WOND vlg FRITSCH 23 cm 45 mm x 75 mm'	1
'GY26'	'SPECULUM vlg DOYEN 24 cm 90 x 35 mm'	7
'GY33'	'SCHAAR PREPAREER vlg ZEPPELIN 23 cm geb'	6
'GY39'	'TANG HAAK vlg POZZI 25,5 cm'	10
'GY41'	'KLEM vlg ZEPPELIN 24 cm'	10
'ON01'	'KLEM LIGASURE 24 cm geb'	1
'ON09'	'TANG PAK WEEFSEL vlg BABCOCK 24 cm'	10
'ON13'	'NAALDVOERDER vlg MAYO HEGAR 24,5 cm'	2
'ON19'	'KLEM 29 cm links geb'	4
'ON29'	'TANG HEMOCLIP 28 cm large gemod'	1
'ON30'	'TANG HEMOCLIP 28 cm large gemod'	1
'ON37'	'PINCET ATRAUM vlg DE BAKEY 30 cm 2,8 mm'	1

Figure 23: Reasons for Unique Recommendations Between Methods - Specialists vs. 10% Data

E Excel Files Data Collection

This appendix provides an overview of the different Excel sheets, as they were used for the user data collection and procedure specifications.

E.1 Overview

Fig. 24 shows the Excel sheet that was used during the initial data collection phase and first risk analysis of the abdominal procedures. Columns A-D provide the names of the different trays and medical instruments as they are presented during these procedures. Column E contains the individual weight of every instrument. These weights were measured to determine the final weight reduction of the contents of the trays. Columns F and G provide the recommended tray reductions by the medical specialists and the OR-assistants, respectively. These values will be used as an input for the comparison and reduction models in Matlab. Column H shows which high-risk items should be exempt from automatic deletion, based on the division between high-risk and low-risk items in Column I. Columns J and beyond contain the actual user data. A '1' states the item was used at least once for a given procedure, whereas a '0' means the item was not used for a given procedure. Missing data points are given a '-1' value, as stated in the Methods section.

E.2 Details of the Procedure

Ideally, a list of necessary items is created for every individual procedure. However, even for identical procedures, several differences can be identified. In the future, these differences may be used to personalize instrument tray recommendations, either for the physician, the patient, required help from other departments, or based on the choice between different disposable instrument alternatives. This sheet summarizes some of the variables between similar procedures, even though the sample size is too small to effectively exploit this variability. Also, the sheet describes use rates for different instrument trays and procedures. Fig. 25 and 26 give an example of these topics for the abdominal procedures. Starting with Fig. 25, columns A-C define the specifics and the date of the procedure. Columns D-F state the length of the procedure, starting at the time of the first incision and ending at the time of wound closure, and column G gives the results of the set-up time measurements. These results can be neglected, because the OR-assistants perform many other tasks during the set-up of the trays, such as the procedural briefing and the unpacking of the other disposable items. Therefore, it was decided to stop measuring set-up times halfway through the research. Columns H-O provide use rates and percentages of both the individual instrument trays and total number of the provided instruments. Lastly, column P defines whether the procedure was performed by a single surgeon (SS), or multiple surgeons (MS). In this case, MS means help from other departments, as opposed to multiple surgeons from a single department. Again, this information can be used to determine whether certain departments require additional instruments.

Fig. 26 continues by showing the medical specialist, OR-assistant and circulatory nurse that performed the specific procedure in columns Q, R and S. Differentiating between the OR-personnel may be used to map differences in procedure times (to be used for scheduling purposes) and instrument usage. The number of the operating room is shown in column T and any additional specialist from column P are further specified in column U. The use of typical disposable bipolar (Ligasure/Enseal) or supersonic (Harmonic) instruments is stated in columns V and X. This information might reveal differences in reusable instrument use in combination with these specific disposables, as opposed to a completely reusable approach. Column W differentiates between 'regular' and HIPEC procedures. The evaluation of the new tray compositions required the additional measurements of door movements, missing instruments and user satisfaction, as depicted in columns Y-AA.

E.3 Risk Analysis

Fig. 27 describes the (new) tray contents during the evaluation phase in columns A and B. Column C gives the number of instrument uses over the 7 procedures during evaluation. Column D divides the items in high- and low-risk items, similar (but opposite) to the veto column in Fig. 24. This information will be used as an input to the risk analysis model in Matlab.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	Naam Net (T-DOC)	Code Net (T-DOC)	Instrument (Matlab)	Instrument (officieel)	Gewicht instrument	Op het net volgens specialisten	Op het net volgens OK assisten	Veto Specialist	Risico voor p	LAT-PR1	LAT-PR2	LAT-PR3	LAT-PR4	LAT-PR5	LAT-P
2	Basisnet Cluster II	SA-1907	BA01	KLEM ARTERIE vlg DANDY 14 cn	26.3	1	1	1	B	-1	-1	1	1	1	
3	Basisnet Cluster II	SA-1907	BA02	KLEM ARTERIE vlg DANDY 14 cn	26.3	1	1	1	B	-1	-1	1	0	1	
4	Basisnet Cluster II	SA-1907	BA03	KLEM ARTERIE vlg DANDY 14 cn	26.3	0	1	1	B	-1	-1	1	0	0	
5	Basisnet Cluster II	SA-1907	BA04	KLEM ARTERIE vlg DANDY 14 cn	26.3	0	1	1	B	-1	-1	1	0	0	
6	Basisnet Cluster II	SA-1907	BA05	KLEM ARTERIE vlg KOCHER 14	28.6	1	1	1	B	-1	-1	1	0	1	
7	Basisnet Cluster II	SA-1907	BA06	KLEM ARTERIE vlg KOCHER 14	28.6	1	1	1	B	-1	-1	1	0	1	
8	Basisnet Cluster II	SA-1907	BA07	KLEM ARTERIE vlg KOCHER 14	28.6	1	1	1	B	-1	-1	1	0	0	
9	Basisnet Cluster II	SA-1907	BA08	KLEM ARTERIE vlg KOCHER 14	28.6	1	1	1	B	-1	-1	1	0	0	
10	Basisnet Cluster II	SA-1907	BA09	TANG PAK WEEFSEL vlg ALLIS	26.1	1	0	0	C	-1	-1	1	0	0	
11	Basisnet Cluster II	SA-1907	BA10	TANG PAK WEEFSEL vlg ALLIS	26.1	1	0	0	C	-1	-1	1	0	0	
12	Basisnet Cluster II	SA-1907	BA11	KLEM DOEK vlg BACKHAUS 13 c	29.4	0	0	1	A	-1	-1	0	0	0	
13	Basisnet Cluster II	SA-1907	BA12	KLEM DOEK vlg BACKHAUS 13 c	29.4	0	0	1	A	-1	-1	0	0	0	
14	Basisnet Cluster II	SA-1907	BA13	KLEM ARTERIE vlg PEAN 14 cm	29.9	0	1	1	A	-1	-1	1	1	0	
15	Basisnet Cluster II	SA-1907	BA14	KLEM ARTERIE vlg PEAN 14 cm	29.9	0	1	1	A	-1	-1	0	0	0	
16	Basisnet Cluster II	SA-1907	BA15	KLEM ARTERIE vlg KOCHER-OC	42.9	0	1	1	A	-1	-1	1	1	1	
17	Basisnet Cluster II	SA-1907	BA16	KLEM ARTERIE vlg KOCHER-OC	42.9	0	1	1	A	-1	-1	1	0	1	
18	Basisnet Cluster II	SA-1907	BA17	KLEM ARTERIE vlg KOCHER-OC	42.9	0	0	1	A	-1	-1	0	0	0	
19	Basisnet Cluster II	SA-1907	BA18	KLEM ARTERIE vlg KOCHER-OC	42.9	0	0	1	A	-1	-1	0	0	0	
20	Basisnet Cluster II	SA-1907	BA19	KLEM PREPAREER vlg HEISS 19	55	1	1	0	D	-1	-1	1	1	1	
21	Basisnet Cluster II	SA-1907	BA20	KLEM PREPAREER vlg HEISS 19	55	1	1	0	D	-1	-1	1	0	0	
22	Basisnet Cluster II	SA-1907	BA21	KLEM PREPAREER vlg HEISS 19	55	1	0	0	D	-1	-1	0	0	0	
23	Basisnet Cluster II	SA-1907	BA22	KLEM PREPAREER vlg HEISS 19	55	1	0	0	D	-1	-1	0	0	0	
24	Basisnet Cluster II	SA-1907	BA23	KLEM ARTERIE vlg CRAFOORD 2	61.6	1	1	0	C	-1	-1	1	0	0	
25	Basisnet Cluster II	SA-1907	BA24	KLEM ARTERIE vlg CRAFOORD 2	61.6	1	1	0	C	-1	-1	0	0	0	
26	Basisnet Cluster II	SA-1907	BA25	NAALDVOERDER vlg MAYO HEG	54.4	1	1	0	D	-1	-1	1	1	1	
27	Basisnet Cluster II	SA-1907	BA26	NAALDVOERDER vlg MAYO HEG	54.4	1	1	0	D	-1	-1	1	1	1	
28	Basisnet Cluster II	SA-1907	BA27	NAALDVOERDER vlg CRILE WOO	32.2	1	1	0	D	-1	-1	1	0	1	
29	Basisnet Cluster II	SA-1907	BA28	NAALDVOERDER vlg CRILE WOO	32.2	1	1	0	D	-1	-1	1	0	1	
30	Basisnet Cluster II	SA-1907	BA29	ZUIGBUIS vlg POOL 22 cm Ø 10	44.3	1	1	0	D	-1	-1	1	1	1	
31	Basisnet Cluster II	SA-1907	BA30	LEPEL KROP vlg KOCHER	75.2	1	1	1	A	-1	-1	0	0	0	
32	Basisnet Cluster II	SA-1907	BA31	HAAK WOND vlg SAUERBRUCH 4	77.5	0	0	1	A	-1	-1	1	0	0	
33	Basisnet Cluster II	SA-1907	BA32	HAAK WOND vlg SAUERBRUCH 4	77.5	0	0	1	A	-1	-1	0	0	0	
34	Basisnet Cluster II	SA-1907	BA33	HAAK WOND vlg FRITSCH 23 cm	199	1	1	1	B	-1	-1	1	0	0	
35	Basisnet Cluster II	SA-1907	BA34	HAAK WOND vlg FRITSCH 23 cm	199	1	1	1	B	-1	-1	0	0	0	

Laparotomie Totaal | Laparotomie Evaluatie | Laparotomie Risico | Laparotomie per Procedure | Laparoscopie Totaal | Laparoscopie per Procedure | +

Figure 24: Overview of Excel Layout for User Data Collection

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Procedure	Specificatie	Datum	Procedure B	Procedure Eir	Procedur	Set-Up Tijd (	Use Aantal Ba	Use Aantal Gyn	Use Aantal On	Use Aantal Tot	Use % Basisn	Use % Gyn ne	Use % Onco n	Use % Instrume	Single Surg
2	LAT-PR1	Hysterectomie/Debulking	07-May	9:30	14:00	270	24	-1	11/43	-1	11/43	-100.00%	25.58%	-100.00%	25.58%	MS
3	LAT-PR2	Debulking	07-May	14:45	16:32	107	15	-1	12/43	-1	12/43	-100.00%	27.91%	-100.00%	27.91%	SS
4	LAT-PR3	Debulking,, hysterectomie, vagi	22-May	10:31	19:00	509	39		17/43		10/45	68/150	72.58%	39.53%	22.22%	48.00%	MS
5	LAT-PR4	Re - Laparotomie	03-Jul	9:20	12:13	173	17		15/62		6/43	9/45	31/150	24.19%	13.95%	20.00%	MS
6	LAT-PR5	radicale uterus extirpatie + deb	04-Jul	12:02	15:30	208	23		24/62		12/43	8/45	45/150	38.71%	27.91%	17.78%	SS
7	LAT-PR6	abdominale uterus extirpatie	09-Jul	9:00	12:25	205	36		26/62		17/43	9/45	53/150	41.94%	39.53%	20.00%	SS
8	LAT-PR7	adnex extirpatie + omentum ve	09-Jul	13:36	15:25	109	27		16/62		12/43	-1	28/105	25.81%	27.91%	-100.00%	MS
9	LAT-PR8	Hipec debulking (ovarium carci	11-Jul	9:46	11:56	130	33		26/62		4/43	3/45	33/150	41.94%	9.30%	6.67%	MS
10	LAT-PR9	Proeflaparotomie + Adnex extir	13-Aug	9:02	12:16	194	-1		27/62		8/43	3/45	38/150	43.55%	18.60%	6.67%	SS
11	LAT-PR10	Proeflaparotomie + adnex extir	13-Aug	13:06	15:18	132	-1		20/62		12/43	5/45	38/150	32.26%	27.91%	11.11%	SS
12	LAT-PR11	Hipec debulking (ovarium carci	03-Sep	10:10	16:20	370	-1		27/62		11/43	2/45	40/150	43.55%	25.58%	4.44%	MS
13	LAT-PR12	abdominale uterus extirpatie	04-Sep	9:56	12:07	131	-1		25/62		14/43	8/45	47/150	40.32%	32.56%	17.78%	SS
14	LAT-PR13	radicale uterus extirpatie + LAD	24-Sep	8:43	11:50	187	-1		28/62		11/43	12/45	50/150	45.16%	25.58%	26.67%	SS
15	LAT-PR14	Adnex extirpatie	24-Sep	12:37	13:31	54	-1		21/62		6/43	-1	26/105	33.87%	13.95%	-100.00%	SS
16	LAT-PR15	Radicale hysterectomie met lyr	25-Sep	8:56	12:30	214	-1		27/62		9/43	9/45	45/150	43.55%	20.93%	20.00%	SS
17	LAT-PR16	Radicale uterus extirpatie met	25-Sep	13:32	16:03	151	-1		24/62		14/43	9/45	47/150	38.71%	32.56%	20.00%	SS
18	Evluatie	Specificatie	Datum	Procedure B	Procedure Eir	Procedur	Set-Up Tijd (	Use Aantal Ba	Use Aantal Gyn	Use Aantal On	Use Aantal Tot	Use % Basisn	Use % Gyn ne	Use % Onco n	Use % Instrume	Single Surg
19	LAT-PR17	Radicale uterus extirpatie + lyr	29-Oct	9:16	13:05	229	-1	25/39	16/26	17/30	58/95	64.10%	61.54%	56.67%	61.05%	SS
20	LAT-PR18	Hysterectomie + dubbelzijdig a	29-Oct	13:52	17:05	193	-1	28/39	12/26	6/30	46/95	71.79%	46.15%	20.00%	48.42%	MS
21	LAT-PR19	Cyste + adnexen extirpatie, pro	30-Oct	12:38	14:03	85	-1	15/39	6/26	4/30	25/95	38.46%	23.08%	13.33%	26.32%	SS
22	LAT-PR20	Interval Debulking HIPEC	31-Oct	9:54	16:17	383	-1	26/39	11/26	8/30	45/95	66.67%	42.31%	26.67%	47.37%	MS
23	LAT-PR21	Debulking	01-Nov	9:01	11:23	142	-1	25/39	9/26	4/30	38/95	64.10%	34.62%	13.33%	40.00%	SS
24	LAT-PR22	Algemene uterus extirpatie + ly	05-Nov	10:44	14:00	196	-1	26/39	15/26	11/30	52/95	66.67%	57.69%	36.67%	54.74%	SS
25	LAT-PR23	radicale uterus extirpatie + LAD	14-Nov	9:10	12:15	185	-1	22/39	11/26	11/30	44/95	56.41%	42.31%	36.67%	46.32%	SS

Figure 25: Overview of Excel Layout for Procedure Specifics

	Q	R	S	T	U	V	W	X	Y	Z	AA
1	Specialist	OK-Assistent	Omloop	OK Nummer	Andere Specialisten	Ligasure/ENSEAL?	HIPEC	Harmonic?			
2	Beltman	Silke	Lisette	9		-1	Nee	-1			
3	Beltman	Bettine	Lisette	9		-1	Nee	-1			
4	Gaarenstroom	Maaike Luijk	Monique	9	PC v Drunen, Ch Peeters, Ur v. Gennep	-1	Nee	-1			
5	Beltman	Anoushka		9	Uroloog v. Gennep	-1	Nee	-1			
6	de Kroon	Marzia	Anouska	9		-1	Nee	-1			
7	Gaarenstroom	Anoushka		9		-1	Nee	-1			
8	Gaarenstroom	Anoushka		9	Kinderarts aanwezig voor C-sectio	-1	Nee	-1			
9	de Kroon	Maaike Luijk	Tine van Beuzekom	9	Peeters van de Heelkunde	-1	Ja	-1			
10	Gaarenstroom	Hanneke	Silke	9		Nee	Nee	-1			
11	Beltman	Silke	Hanneke	9		Ja	Nee	-1			
12	Beltman	Hanneke	Karin	3	Peeters van de Heelkunde	Ja	Ja	-1			
13	Beltman	Tessa	Marjolein	9		Ja	Nee	-1			
14	de Kroon	Anouska	Bettine	9		Ja	Nee	-1			
15	de Kroon	Bettine	Anouska	9		Nee	Nee	-1			
16	de Kroon	Karin	Marjolein	9		Ja	Nee	Ja			
17	de Kroon	Marjolein	Karin	9		Nee	Nee	Ja			
18	Specialist	OK-Assistent	Omloop	OK Nummer	Andere Specialisten	Ligasure/ENSEAL?	HIPEC	Harmonic?	Aantal Deurbewegingen	Specialisten tevreden?	Welke extra instrumenten nodig?
19	Gaarenstroom	Julia	Lisette	9	nvt	Nee	Nee	Ja	34	Ja	Geen
20	Gaarenstroom	Lisette	Julia	9	Chirurg	Enseal	Nee	Nee	39	Ja	Geen
21	Beltman	Julia	Maaike	9	nvt	Ligasure	Nee	Nee	16	Ja	Geen
22	de Kroon	Karin	Maaike	9	Holman, chirurg	Enseal	Ja	Nee	63	Ja	Geen
23	de Kroon	Marzia	Marjolein	9	nvt	Ligasure	Nee	Nee	24	Ja	Geen
24	Beltman	Julia	Renske	9	nvt	Ligasure	Nee	Nee	37	Ja	Geen
25	de Kroon	Julia	Lisette	9	nvt	Nee	Nee	Ja	18	Ja	Geen

Figure 26: Overview of Excel Layout for Procedure Specifics

	A	B	C	D	E
1	Naam Matlab	Naam T-DOC	Aantal keer gebruikt tijdens evaluatie (n=7)	Hoog Risico? (1 ja/ 0 nee)	
2	BA01	KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb	7	0	
3	BA02	KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb	6	0	
4	BA03	KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb	0	0	
5	BA04	KLEM ARTERIE vlg DANDY 14 cm zijwaarts geb	0	0	
6	BA05	KLEM ARTERIE vlg KOCHER 14 cm	6	0	
7	BA06	KLEM ARTERIE vlg KOCHER 14 cm	6	0	
8	BA07	KLEM ARTERIE vlg KOCHER 14 cm	4	0	
9	BA08	KLEM ARTERIE vlg KOCHER 14 cm	2	0	
10	BA09	TANG PAK WEEFSEL vlg ALLIS 15 cm	2	1	
11	BA10	TANG PAK WEEFSEL vlg ALLIS 15 cm	0	1	
12	BA11	KLEM DOEK vlg BACKHAUS 13 cm	0	0	
13	BA12	KLEM DOEK vlg BACKHAUS 13 cm	0	0	
14	BA13	KLEM ARTERIE vlg PEAN 14 cm geb	0	0	
15	BA14	KLEM ARTERIE vlg PEAN 14 cm geb	0	0	
16	BA15	KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb	7	0	
17	BA16	KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb	5	0	
18	BA17	KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb	0	0	
19	BA18	KLEM ARTERIE vlg KOCHER-OCHSNER 18 cm geb	0	0	
20	BA19	KLEM PREPAREER vlg HEISS 19,5 cm geb	6	1	
21	BA20	KLEM PREPAREER vlg HEISS 19,5 cm geb	2	1	
22	BA21	KLEM PREPAREER vlg HEISS 19,5 cm geb	0	1	
23	BA22	KLEM PREPAREER vlg HEISS 19,5 cm geb	0	1	
24	BA23	KLEM ARTERIE vlg CRAFOORD 24,5 cm geb	6	1	
25	BA24	KLEM ARTERIE vlg CRAFOORD 24,5 cm geb	3	1	
26	BA25	NAALDVOERDER vlg MAYO HEGAR 20 cm	7	1	
27	BA26	NAALDVOERDER vlg MAYO HEGAR 20 cm	4	1	
28	BA27	NAALDVOERDER vlg CRILE WOOD 15 cm	7	1	
29	BA28	NAALDVOERDER vlg CRILE WOOD 15 cm	5	1	
30	BA29	ZUIGBUIS vlg POOL 22 cm Ø 10 mm	1	1	
31	BA30	LEPEL KROP vlg KOCHER	1	0	
32	BA31	HAAK WOND vlg SAUERBRUCH 46 x 16 mm	0	0	
33	BA32	HAAK WOND vlg SAUERBRUCH 46 x 16 mm	0	0	
34	BA33	HAAK WOND vlg FRITSCH 23 cm 45 mm x 75 mm	3	0	
35	BA34	HAAK WOND vlg FRITSCH 23 cm 45 mm x 75 mm	1	0	

Laparotomie Totaal | Laparotomie Evaluatie | **Laparotomie Risico** | Laparotomie per Procedure | Laparoscopie Totaa

Figure 27: Overview of Excel Layout for Second Risk Analysis