ISYE 4106 Senior Design Final Report

Piedmont Atlanta Hospital

Sterile Processing Department Quality Assurance and Resource Allocation Measures to Reduce Tray Defects and Surgery Delays

Executive Summary

The client, Piedmont Atlanta Hospital (PAH), is a 643-bed, private, not-for-profit hospital serving the metro Atlanta community. The team worked with the hospital's Sterile Processing Department (SPD) to reduce surgery delays related to the department and ensure efficient operations. SPD is responsible for cleaning and sterilizing all instruments used in medical procedures.

In 2021, 4.7% of surgeries were delayed due to SPD while the average delay time for all first surgeries of the day was 22.1 minutes. 3.37% of all SPD delays were due to tray defects, and 1.33% of them were due to a case cart not arriving at the Operating Room (OR) on time. A tray defect is a tray that cannot be used in the OR due to human error when assembling a tray in SPD, while on-time case cart delivery is affected by tray unavailability.

The team's first objective was to reduce the total number of tray defects caused at or before the Assembly Station to reduce the number of surgery delays. Since there were no quality assurance measures in place, the team implemented a quality assurance checklist at the end of the Assembly station to prevent defective trays from reaching the OR. The client conducted a month-long implementation period from March 7th to April 7th. During this period, the team reached a 22.53% delay rate reduction from 2021 and 23.01% reduction from the beginning of 2022, leading to a projected savings of $1.37 million over the next 12 months.

The second objective was to ensure an on-time delivery of case carts to the OR. The team narrowed the scope to focus only on the neurosurgery service line and created a simulation model using Simio to determine the optimal number of neurosurgery trays and instrument technicians at Decontamination and Assembly that achieves a minimum 95% fill rate for 3 OR capacity levels. An Excel dashboard was created to provide the client with the recommended labor and neuro-tray levels depending on the hospital's capacity level. Thus, the team recommends a reallocation of labor from Assembly to Decontamination with a 14.1%, 28.1%, and 28.7% increase in the top 50 most used trays for 60%, 70%, and 80% capacity levels, respectively. Implementing the tray and labor recommendations for 60% capacity results in a projected savings of $3.31 million for 2022.

The quality assurance checklist enables the client to prevent defective trays from causing surgery delays, while the capacity planning dashboard assists the client with its long-term planning decisions as they begin to increase their number of scheduled surgeries to recover from the pandemic.

Table of Contents

1. Project Overview and System Description

1.1. Client Context

The client, Piedmont Atlanta Hospital (PAH), is the third largest hospital in Georgia, and it is one of 16 hospitals in the Piedmont Healthcare network. Across their network, they see over 2.7 million patients and perform over 88,000 surgeries per year. The project will focus on PAH's Sterile Processing Department (SPD), where technicians clean medical instruments[1] from previous surgeries and prepare them for future operations.

1.2. Current System Description

All instruments that are used in the Operating Room (OR) must go through SPD to be cleaned, and similarly, all instruments cleaned in SPD are then used again in the OR. Demand for these instruments is determined by surgeons, who create preference cards for upcoming surgeries and send them to SPD, where technicians will prepare instruments based on the surgeon's requests as listed on the preference cards. Instruments make their way to and from the OR in trays that also contain filters and chemical indicators such as locks that indicate whether a tray is sterile. These trays are transported to the OR in carts, which also contain all other needed supplies for a given surgery. Throughout the SPD, trays are regularly scanned into PAH's inventory tracking system, SPM (Sterile Processing Microsystem), so that their location and status can be tracked. Figure 1 below shows the process flow chart of SPD.

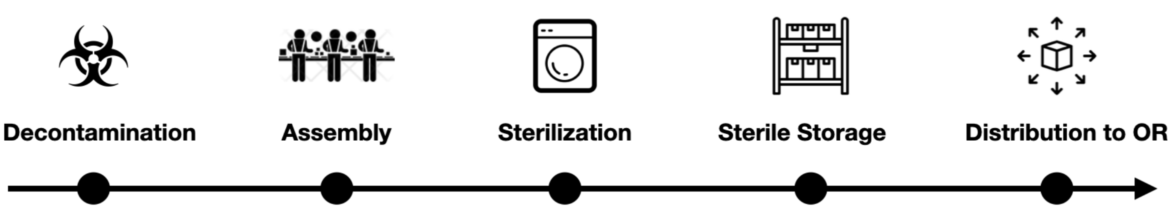


Figure 1: SPD Flow Chart

Decontamination: Once a surgery is completed, the instruments and trays are immediately sent down to SPD from the OR and must be decontaminated within an hour. Instruments are washed in decontamination sinks, ultrasonic cleaners, and washers/disinfectors based on manufacturer specifications. Decontamination ensures that soiled instruments are hygienic by eliminating microbial contamination.

Assembly: The decontaminated trays of instruments are transferred to a rack next to the 12 Assembly worker stations where technicians select a tray to assemble based on the First-In, First-Out (FIFO) method. However, if a tray is immediately needed for a surgery, technicians will process this tray first.

[1] All words in green are defined in Appendix A.

After selecting a tray, they will inspect the instruments for dirt and debris and then proceed to pack these instruments into their assigned trays based on the count sheet that specifies the needed quantities of each instrument.

Sterilization: After Assembly, the completed trays are moved into one of five steam sterilizers or one of three low-temperature sterilizers to remove any remaining living organisms from the medical instruments. Trays are loaded into sterilization machines together if they have the same sterilization time, and the priority of tray processing is based on the upcoming surgery schedule.

Sterile Storage: In Sterile Storage, the trays are taken out of the sterilizers and put on a timer for 36 minutes for the trays in the load to cool down. If the trays are not immediately required for a surgical procedure, the technicians store them on shelves. Because the storage shelves are divided by service line (e.g., Orthopedic, Neurological, etc.), the location of tray storage depends on the type of surgery the tray is used for. The average weekly volume of trays placed in storage at SPD is 2,911.

Distribution: In the distribution area, trays are placed onto case carts based on surgeon preference cards. These case carts are then sent to the OR prior to the start of their respective surgeries.

OR Capacity: Due to the pandemic, the hospital is currently operating at 60% OR capacity by limiting surgery scheduling to weekdays. Under normal circumstances, PAH operates at 80% of its OR capacity with a 20% buffer for emergency cases.

1.3. Engineering Standards

The SPD follows a set of requirements, specifications and guidelines established by the Association for the Advancement of Medical Instrumentation (AAMI). Additionally, the team referenced ISO 2859 when constructing the first design module. A detailed list of engineering standards is in Appendix B.

1.4. Client Concern

The client's primary concerns are the late arrival of case carts to the OR and trays arriving to the OR with tray defects, which both lead to surgery delays. Tray defects are trays that arrive and cannot be used in the OR due to human error in SPD, such as missing instruments and contaminated trays. Case carts fail to arrive at the OR on-time when trays required for an upcoming surgery are not ready. Trays are only available if they contain no missing instruments or have successfully completed the sterilization cycle and are either cooling or in sterile storage; hence, not in Decontamination, Assembly, Sterilization, or the OR. In 2021, 4.7% of surgeries were delayed due to SPD with an average delay time of 22.1 minute for all first surgeries of the day. Of the total SPD delays, 3.37% of surgery cases had tray defects due to the Assembly process, while 1.33% of cases did not have a case cart arrive at the OR on time. Design Module 1 focused on reducing the number of tray defects by implementing a quality assurance checklist, while

Design Module 2 focused on improving the on-time delivery of case carts by developing a resource planning tool.

2. Design Module 1: Quality Assurance Checklist

2.1. Opportunity

There are no quality assurance measures in place at SPD, even though 71.7% of all SPD-related delays were due to tray defects. These defects occur at or before the Assembly process which consists of four tasks.

1. Inspection: Technicians inspect trays for bioburden. If trays are found to be contaminated, they must be sent back to Decontamination.
2. Functionality check: Checks are performed according to manufacturer standards. If an instrument is broken or damaged, it must be sent for repair.
3. Instrument placement: Instruments must be placed back into trays based on a count sheet. This count sheet is present in SPM, but a printed version must also be added to the tray. Here, human error can result in missing or wrong instruments being placed into trays.
4. Sterilization preparation: Technicians prepare the trays for sterilization by wrapping or locking them and adding the filters and chemical indicators, which indicate proper sterilization. Any tampering with the lock or tears in the wrapping result in contaminated trays.

The team received tray defect data from OR reports covering the year 2021 and analyzed the data based on defect type. A total of 20,238 surgeries were performed in 2021 with a total of 462,789 trays processed in 2021, and a total of 682 identifiable tray defects were recorded out of the 20,238 surgeries. Of the Assembly defects, 69.79% of total defects were due to missing instruments and 26.98% were due to contaminated trays. An analysis of the Assembly process can be found in Appendix C. To tackle this opportunity, the team implemented a quality assurance checklist at the end of the Assembly process in which the primary success metric was the reduction in the number of tray defects. This checklist would effectively catch defects before they enter the OR, saving time as well as preventing surgery delays.

2.2. Objective

This module's objective was to reduce the number of tray defects occurring at Assembly to prevent surgical delays caused by defective trays arriving at the OR.

2.3. Design Requirements

Hard Constraints: The existing procedures related to sterilization, wrapping, packing, and instrument testing were hard constraints, as these were prescribed by medical or instrument manufacturing standards. The team was also instructed not to add any Assembly stations or instrument technicians for the purpose of quality assurance. Lastly, any software-related solutions to be used by instrument technicians must be integrated into the inventory management software they currently use, SPM.

Soft Constraints: The team was required to minimally impact the workflow and processing speed of technicians at the Assembly station; hence, the team avoided significant changes to the current standard operating procedure that would cause lengthy adjustment periods for technicians. A list of all the constraints can be found in Appendix D.

2.4. Data

To collect data, the team conducted many client visits: observing the system, shadowing technicians, and interviewing stakeholders. Specifically, the team conducted semi-structured interviews with the SPD manager, SPD technicians, SPD supervisors and SPD OR liaisons to validate the identified causes of tray defects and potential solutions. In addition, the team conducted thorough reviews of regulations and guidelines concerning sterile processing standard operating procedures. Moreover, the team collected data on all delays recorded in 2021 and analyzed and categorized the surgery delays caused by SPD based on tray defects. More information on the tray defect analysis process is in Appendix E.

2.5. Methodology

The team conducted a literature review on the implementation of quality assurance measures at various hospitals. A research study indicated that adding a worker station for quality assurance after Assembly would make a large impact on the reduction of tray defects (Blackmore, Bishop, Luker, & Williams, 2013). However, the team was instructed not to add any stations or quality assurance technicians by the client. Instead, the team produced a paper-based quality audit checklist that supervisors could use by performing random checks during each shift. Design alternatives for this module can be found in Appendix F.

Checklist: The checklist is divided into external quality audit and internal quality audit sections. The external quality audit makes sure that the tray is properly wrapped and locked to prevent holes in the wrap and broken locks, thus reducing the number of contaminated trays. The internal quality audit inspection involves confirming that everything (filters, a count sheet, a chemical indicator, and instruments) is placed inside trays. This will reduce the number of missing instruments and contaminated instruments, hence, reducing surgery delays. In addition, to mitigate the risk of disrupting workflow or increasing processing time at Assembly, the team made the checklist simple and generalizable for all service lines, with yes or no questions that apply to all trays. The checklist can be found in Appendix G.

Pilot Study: After finalizing the checklist, the client agreed on its implementation for a period of one month from March 7th to April 7th. ISO 2859, a quality inspection standard, prescribes 50 random checks per day given the current system throughput, but since the client stated that this was not currently feasible with their current staffing levels, the client and the team agreed to implement this pilot run with five checks per shift or 15 checks per day. During this period, the team used reduction of tray defects and consequent reduction of surgery delays as the key success metrics. In addition, a pre-implementation and post-implementation survey was conducted to assess human impact on technicians. This survey employed a Likert scale across four different categories: Workflow, Reduction in Human Error, Accountability, and Satisfaction. These categories were determined through talking to the client to identify main areas of concern. The survey itself can be found in Appendix H.

2.6. Results and Discussion

After the month-long implementation, data was collected on surgery delays and then manually sorted as described in Appendix E. This data showed that the daily delay rate was 1.47 during the pilot period, which was a 22.53% improvement from 2021 and a 23.01% reduction from the start of 2022 up until March 7th, the start of the implementation. In the implementation period of a month, 17 defects were caught and prevented through the quality audit checklist. To measure client satisfaction, the pre-implementation and post-implementation survey had three different categories: Workflow, Reduction in Human Error, and Accountability. Each category was ranked from 1 to 4, from worst to best. Below is the table with the results.

Table 1: Survey Results

Categories	**Pre-implementation**	**Post-implementation**
Workflow	2.16	2.16
Reduction in Human Error	3.26	3.53
Accountability	3.03	3.51
Satisfaction	N/A	3.63

Workflow remained the same after the pilot, indicating that the checklist had minimal impact on the workflow, while both Reduction in Human Error and Accountability increased. Lastly, Satisfaction was almost a four, indicating that the technicians thought that the quality assurance checklist had a large impact in decreasing the number of tray defects. Appendix I contains future recommendations regarding the checklist and its implementation.

3. Design Module 2: Resource Planning Model

3.1. Opportunity

The root causes behind delayed case carts are limited resources of labor and trays. The team identified three symptoms associated with this cause:

1. Long SPD cycle times from Decontamination to Sterilization: The average realized cycle time was 471 minutes with the 25th percentile at 225 minutes and the 75th percentile at 525 minutes, whereas the ideal cycle time should be between 180 to 240 minutes. In 2021, SPD was understaffed by 18.3%, which limits the number of trays that can be processed simultaneously and increases tray cycle times.
2. Backlog of trays throughout the system: SPD currently operates during the weekends to catch up on tray processing to both reduce the backlog of trays accumulated over the past week, which can be attributed to the department being understaffed.
3. Surgery delays due to SPD: There was a 5.2% decrease from 2019 to 2021 in the overall fill rate (which is the primary metric for this module) for all surgeries performed at PAH, and the fill rates for the three most profitable service lines declined as well (Appendix J). Insufficient tray levels result in tray unavailability for concurrent surgeries leading to delays in surgeries.

3.2. Objective

The objective was to determine the optimal neurosurgery tray levels and number of instrument technicians at Decontamination and Assembly for all shifts to meet a minimum 95% fill rate for 60%, 70%, and 80% OR capacity levels compared to the current 90% fill rate. To do this, the team created a simulation model in Simio and used OptQuest to find the optimal tray and labor level combination. The team also built an accompanying Excel dashboard for the client that displays the recommended levels. Design alternatives for this module can be found in Appendix K.

3.3. Data and Constraints

All data was provided by SPD and the OR and was collected from their SPM and EPIC databases. Details on the types of data collected and data cleaning strategies utilized can be found in Appendix L. Additionally, for a list of all the hard and soft constraints, please refer to Appendix D.

3.4. Methodology

Scope: The team decided to narrow down the project scope to the neurosurgery service line. Based on surgeries performed in 2021, the two longest surgeries among all service lines were neurosurgeries with durations of 754 minutes and 723 minutes, respectively. The 723-minute-long surgery was performed 181 times as the most frequently performed neurosurgical procedure in 2021. Additionally, the team conducted interviews with SPD employees and found that assembling neurosurgery trays was more labor-intensive due to their complex tray configurations. Within the neurosurgery service line, there were 75 different procedures, each requiring 2 to 15 trays and each tray containing up to 200 instruments to assemble.

Simulation Structure: SPD was modeled as a closed-loop system with two types of entities in constant circulation, Neuro Trays and Other Trays, where Other Trays represented other service lines to simulate realistic WIP levels at each SPD function. The model contained six servers to represent the SPD and OR stations. Decontamination was split into two servers to separate technician-run operations at Decontamination Hand Wash (DHW) from the machine-run operations at Decontamination Washer. In addition, sterilization pallets were created to batch trays prior to entering the sterilizers, while case carts were created for each surgery. After Sterilization, trays waited in a Storage queue until they were batched onto case carts nine hours before the scheduled surgery start time. Once batched, the case carts were transferred to the OR queue until the surgery began. In the model, only the capacities at DHW and Assembly depended on the number of technicians assigned to each station. For more details on the simulation structure and implementation see Appendix M.

Data: The model used three main data input tables: (1) 2021 OR Neurosurgery Schedule, which included the surgery name, start time, duration, and tray preference card information; (2) Surgeon Preference Cards, which included a list of all trays requested for a surgery depending on the surgeon; and (3) Tray Information, which listed all 143 neuro trays and their current quantities.

Processing Times: After analyzing SPM timestamp data, Decontamination Washer and Sterilization had fixed machine processing times of 95.28 and 89.58 minutes, respectively. Using Steris time studies, the DHW and Assembly stations had fixed tray processing times of 8.5 and 17 minutes respectively (Appendix N). By referencing the OR schedule, the processing time at the OR was determined by the surgery duration associated with the case cart in use.

Work Schedule: The work schedule consisted of three weekday shifts and two weekend shifts. The number of technicians at each station was a control variable set to current SPD labor levels determined by time studies conducted over the course of two weeks (Appendix O). Using the work schedule, the model assigned a specific number of technicians to each station for all five shifts. The maximum capacity at DHW and Assembly were set to 4 and 12, respectively.

Statistics: The metrics calculated in the model were fill rate, the number of delays, total delay time, and the average number of trays waiting in the queue at DHW.

OR Capacity Adjustments: To aid PAH in planning their recovery from the pandemic, the team ran the model at 70% and 80% of Piedmont's OR capacity. This was done by scaling up the number of surgeries from the baseline model of 60% OR capacity and adding weekend neuro surgeries to the OR schedule. (Appendix P)

OptQuest Implementation: The decision variables were the number of Neuro Trays per tray type and the number of technicians at DHW and Assembly per shift. The model used OptQuest to optimize the tray levels for the 50 most used trays out of the 143 neuro trays used in 2021. The top 50 were selected as they cover approximately 90% of all neuro tray usage. The objective functions were to maximize the neuro fill rate and minimize the total cost made up of SPD labor cost, tray purchasing cost, and surgery delay cost (Appendix Q).

OptQuest Constraint Decisions: The constraints employed can be found in Appendix R.

Model Assumptions: The number of case carts created at the Case Cart Source was equivalent to the number of neurosurgeries in the OR surgery schedule; this was under the assumption that case carts were always readily available. Fixed processing times were also used at DHW and Assembly. Initially, the distributions for processing times at DHW and Assembly were calculated using SPD timestamp data. However, because they included waiting times of trays, they could not be used as they would inflate tray cycle times (Appendix S). In addition, no emergency surgeries were used in the model, and trays were processed at stations using FIFO. A comprehensive list of all assumptions made is in Appendix P.

3.5. Results and Discussion

Model Validation: The simulation ran for two bi-monthly periods, January-February, and May-June, which had the highest and lowest fill rates of 96.5% and 89.4% respectively. Using the confidence interval precision formula to calculate the minimum required replications, the model ran for 207 and 29 replications for January-February and May-June respectively (Appendix T). As shown in Table 2, the true number of delays and fill rate fell within the respective 95% confidence intervals for both periods.

Table 2: Model Validation Results on Number of Delays and Fill Rate

	Number of Delays			Fill Rate		
	Actual	**Mean**	**95% CI**	**Actual**	**Mean**	**95% CI**
Jan-Feb	9	8.09	[6.925, 9.249]	0.9654	0.9690	[0.964, 0.973]
May-Jun	33	30.24	[25.389, 35.091]	0.8940	0.9030	[0.888, 0.919]

OptQuest Results: Running the baseline model in OptQuest for a maximum of 100 replications, the optimal tray and labor levels were selected based on the lowest total cost incurred and highest fill rate achieved. As shown in Figure 2, the recommended number of technicians at DHW for the 7:00am-3:30pm weekday shift and the 7:00pm-7:00am weekend shift did not change from the current labor allocation. The recommended number of technicians for the remaining weekday and weekend shifts, however, increased from 2 to 3, while for all five shifts, the optimal number of technicians at Assembly decreased from 8 to 6. Additionally, the team saw a 14.1% increase in the total number of neuro trays that SPD should add to their system. It was also observed that there was no difference in the recommendations when comparing the most used trays to the least used trays. Running the baseline model with the optimal tray and labor levels, the average number of trays in the DHW queue decreased from 38 to 14. The OptQuest results on the optimal tray levels for 70% and 80% capacity levels are in Appendix U.

Shift	Timing
1	7:00am – 3:30pm
2	3:00pm – 11:30pm
3	11:00pm – 7:30am
4	7:00am – 7:00pm
5	7:00pm – 7:00am

1,2,3 – Weekday
4,5 - Weekend

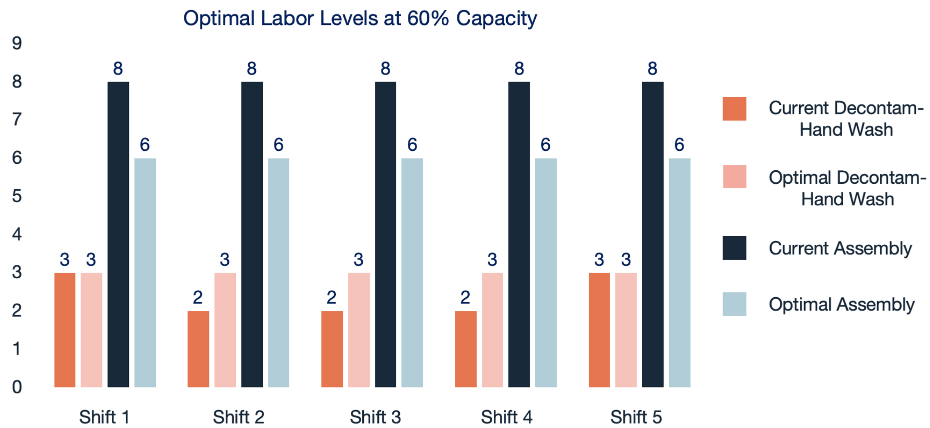


Figure 2: Recommended Labor Levels Per Shift at 60% Capacity

Key Takeaways: Given that technicians are trained to work at any station, SPD should reallocate their labor from Assembly to Decontamination. Because all neurosurgeries end by 7:00pm, the increase in labor levels at Decontamination is imperative during the 3:00pm-11:30pm and 11:00pm-7:30am weekday shifts to process the backlog of trays from during the day. Likewise, it is also important for DHW to have more labor during the 7:00am-7:00pm weekend shift to catch up on tray processing. Please refer to Appendix U for recommendations at 70% and 80% levels.

Model Limitations: The team used market prices to determine tray purchasing costs due to a lack of data; therefore, these prices may not accurately reflect purchase agreements with tray vendors. In addition, because the time stamp data the team received to compute processing time distributions was incomplete, fixed processing times were instead used at the DHW and Assembly. Therefore, the lack of data prevented the team from accounting for variation in technician knowledge and expertise in the model. Finally, prioritization of emergency surgeries was not considered in the system, which is not a complete representation of SPD operations. Due to this, there may have been an underestimation of the optimal resource levels as more trays may be required for such circumstances. A more extensive evaluation of the model can be found in Appendix V.

3.6. Deliverable

The team built an Excel dashboard to visualize the results of the simulation model at 60, 70, and 80 percent OR capacity levels. By selecting the desired capacity level, the dashboard will display the optimal tray quantities for each tray type, the optimal number of workers at DHW and Assembly at each shift, as well as the achieved fill rate and total incurred cost (Appendix W). The dashboard serves as a valuable tool for management to make strategic resource planning decisions.

4. Project Valuation and Impact

After conducting a literature review on the cost of time lost in the OR and adapting for industry specific cost levels (PwC, 2021), the team has calculated the value of a lost minute in the OR to be $301.942 (Appendix X) and applied this to the expected reduction in delays from both deliverables to calculate a total financial value (Girotto, Koltz, Drugas, 2010). As previously mentioned, the pilot initiative that lasted for a month prevented 17 tray defects from being sent to the OR, directly leading to 17 SPD prevented delays. This led to a projected savings of $1.37 million over the next 12 months (Appendix Y), based on the value of saved time in the OR from reduced surgery delays, and the team's conservative estimate of no further improvements in the tray defect rate. Moreover, the implementation survey results indicated that technicians believed the checklist would increase accountability and significantly reduce tray defects while having no impact on workflow and processing times at Assembly.

Regarding the resource planning model, the team assessed the value of the generated recommendations by running the baseline model with the optimal resource allocation as well as the actual resource allocation on the two bi-monthly periods with the lowest and highest fill rates. The team then calculated the average bimonthly fill rates and costs for both resource allocation levels using this data. The team found the average annual fill rate for the optimal allocation to be around 99.84%, which was an improvement of 9.84% over the actual fill rate of 90%. The optimal resource allocation had a total cost of $1,182,202.06 compared to an annual cost of $4,290,190.68 for the actual resource allocation (Appendix Z). This corresponds to $3,107,988.62 in total savings in 2021 which extrapolates to $3,310,007.88 in 2022. Apart from direct financial value, the capacity planning integrated into the resource planning model will give the client advanced planning capabilities well into the future. This will allow them to minimize SPD costs well into the future, leading to enhanced revenue, but will also provide strategic value, since PAH will be able to more accurately predict their costs, capacity, and delays ahead of time, allowing for more accurate decision-making.

Both design modules constructed by the team will have positive effects on patients. Since surgery delays typically result in more patient wait time, the reductions in surgery delays achieved by Design Modules one and two will decrease patient wait time and thus increase patient satisfaction. A study (McIsaac, 2017) has also shown that delays for emergency or urgent surgeries lead to an increase in mortality rates and hospital costs. Mortality rates for surgeries with delays were 4.9% compared to only 3.2% for those without delays, and hospital costs increased by an average of $1,490 for delayed surgeries. Thus, both design modules will increase patient health outcomes and decrease surgery costs.

5. References

Blackmore, C. C., Bishop, R., Luker, S., & Williams, B. L. (2016, November 16). *Applying lean methods to improve quality and safety in surgical sterile instrument processing*. The Joint Commission Journal on Quality and Patient Safety. Retrieved February 25, 2022, from https://www.sciencedirect.com/science/article/pii/S155372501339014X

Girotto, J. A., Koltz, P. F., & Drugas, G. (2010). Optimizing your operating room: or, why large, traditional hospitals don't work. International journal of surgery (London, England), 8(5), 359–367. https://doi.org/10.1016/j.ijsu.2010.05.002

McIsaac, D. I., Abdulla, K., Yang, H., Sundaresan, S., Doering, P., Vaswani, S. G., Thavorn, K., & Forster, A. J. (2017). Association of delay of urgent or emergency surgery with mortality and use of health care resources: a propensity score-matched observational cohort study. CMAJ : Canadian Medical Association journal = journal de l'Association medicale canadienne, 189(27), E905–E912. https://doi.org/10.1503/cmaj.160576

PwC. (2021, June). Medical cost trend: Behind the numbers 2022. PwC. Retrieved April 17, 2022, from https://www.pwc.com/us/en/industries/health-industries/library/behind-the-numbers.html

6. Appendix

Appendix A: Glossary

1. **Backlog**: The accumulation of trays in any SPD station due to a buildup of a station's queue.
2. **Bioburden**: The degree of microbial contamination on a material before undergoing sterilization.
3. **Case Carts**: Carts used to transport trays and other medical supplies needed from the Sterile Processing Department (SPD) to the Operating Rooms (ORs).
4. **Count Sheets**: Sheet with the quantities of needed instruments for a tray.
5. **Delay Cost**: The cost per minute of having a surgery delayed.
6. **Fill Rate**: The percentage of surgery demand met by immediate tray availability for on-time surgery starts

$$Fill\ Rate = \frac{Total\ Number\ of\ Surgeries - Number\ of\ Surgery\ Delays\ Due\ to\ SPD}{Total\ Number\ of\ Surgeries} \times 100\%$$

7. **Instrument Technicians**: People that work in the Sterile Processing Department (SPD) to decontaminate, assemble, sterilize, and store trays along with the surgical instruments.
8. **Instruments**: Any apparatus used for medical purposes.
9. **OptQuest**: An optimization tool provided within Simio.
10. **Purchasing Cost**: The cost associated with buying a new tray.
11. **Service Lines**: Various surgery specialty types including but not limited to neuro, cardio, and obstetrics.
12. **Simio**: A simulation software tool for building and executing dynamic models of systems.
13. **SPD Labor Cost**: The hourly cost associated with paying an SPD worker.
14. **SPD OR Liaison**: People in charge of the communication between the Operating Rooms (ORs) and the Sterile Processing Department (SPD) regarding any tray defects.
15. **Steris**: A medical equipment provider of products and services relating to the sterilization of surgical products.

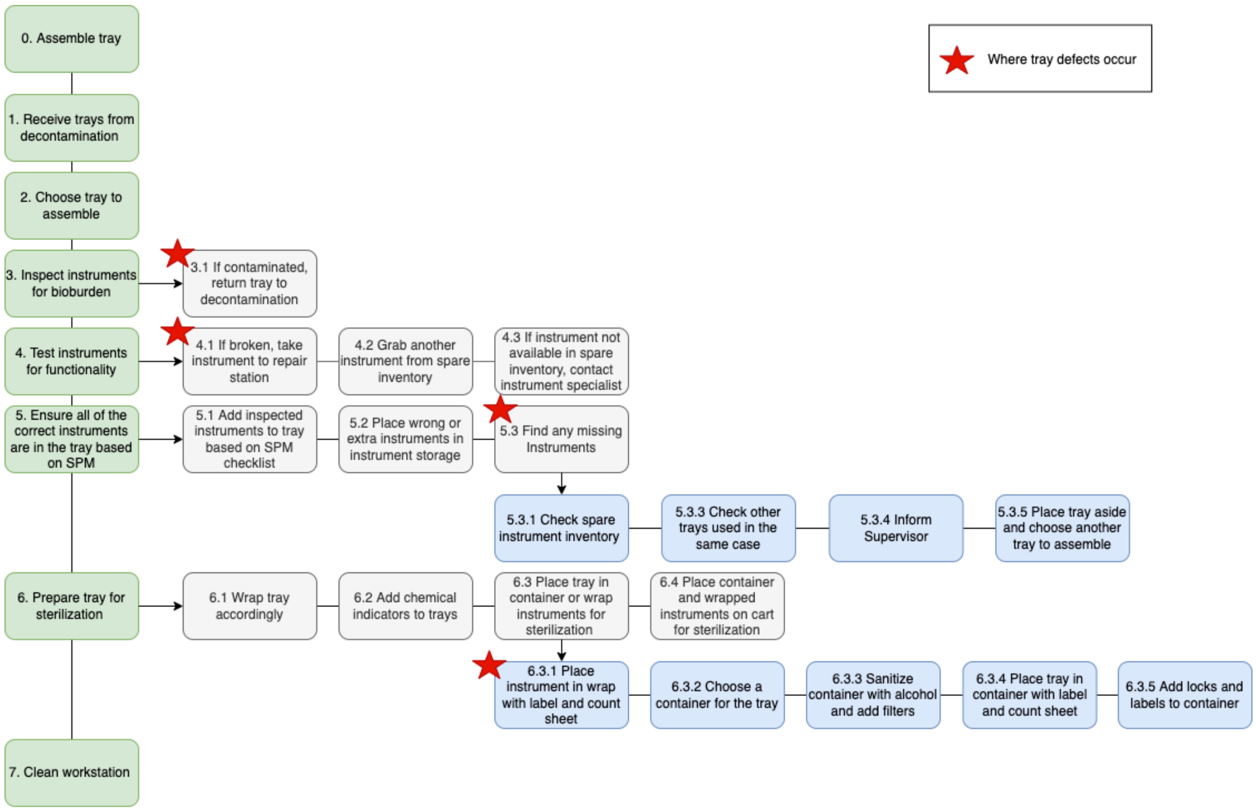
16. **Tray Configurations**: The makeup of a tray including the types of instruments that the tray consists of.
17. **Trays**: Containers that are used to store medical instruments.
18. **WIP**: The work-in-progress of a particular system or process

Appendix B: Engineering Standards Table

Table B1: Sterile Processing Design Standards

Standard	Comments and relevance section
AAMI (Association for Advancement of Medical Instrumentation)	Provide requirements, specifications, guidelines, or characteristics that can be used consistently to ensure that materials, products, processes, and services are fit for their purpose; Aims at enhancing the safety, efficacy, safe use and management of medical devices and health technologies
FGI (Facility Guidelines Institute)	Developing guidance for the planning, design, and construction of hospitals, outpatient facilities, and residential health, care, and support facilities
IFU (Instructions for use)	Guidelines from the FDA on how to clean and reach parameters of sterilization of instruments
AORN (Association of periOperative Registered Nurses)	Develop evidence-based guidelines to support perioperative teams to provide quality sterile processing practices to reduce patients risk of surgical site infection
US Food and Drug Administration (FDA)	Provide guidelines and recommendations for reprocessing instructions for reusable medical devices
Center of Disease Control (CDC)	Guidelines for Disinfection and Sterilization in Healthcare facilities
OSHA (Occupational Safety and Health Administration)	Ensures safe and healthful working environments and conditions for workers
ISO 2859	Sets standards and provides quantitative guidelines for quality inspection

Appendix C: Assembly Flow Chart



Appendix D: Hard and Soft Constraints Tables

Table D1: Soft Constraints

Soft Constraints	Comments and Relevance	Module
Assembly Workflow	The workflow in assembly should be minimally impacted.	Design Module 1
Number of workers in SPD	The number of workers is currently fixed, but this is subject to change if the simulation model recommends a different number of technicians in SPD.	Design Module 2
Capacity of Piedmont and SPD (due to COVID	Because the hospital is currently operating at 60% capacity, the simulation model will only	Design Module 2

Restrictions)	consider a capacity level of at least 60%. It will also account for an extrapolation of a full capacity hospital post-COVID.	
Number of sink stations utilized at DHW	There are four sink stations in use to rinse and soak instruments with the enzymatic solution. This number is set as the maximum capacity allowed at DHW in the simulation model.	Design Module 2
Number of stations utilized at Assembly	There are currently 6-8 stations in use, which will be a constraint in the simulation model and QA analysis. This number however is subject to change as SPD has a total of 12 Assembly stations available.	Design Module 2
Number of trays held in Storage	SPD should have trays in storage, but if they do not have enough, this becomes a constraint that impacts the fill rate.	Design Module 2

Table D2: Hard Constraints

Hard Constraints	Comments and Relevance	Module
Instrument testing procedures	These must be adhered to in agreement with AAMI and IFU guidelines. All instruments must go through adequate testing before being used in the OR.	Design Module 1
Chemical testing procedures, Sterilization procedures	These must be done on all instruments in accordance with AAMI, IFU, FDA, and CDC guidelines.	Design Module 1
Wrapping/Packing methodology	These must be done on all instruments in accordance with AAMI, IFU, FDA, and CDC guidelines.	Design Module 1
Instruments in trays are	The team is not able to change both the	Design Module 1

fixed	number and type of instruments that make up the different tray types.	
Number of Assembly workers	The number of workers is currently fixed. The team cannot hire or reassign workers specifically for quality assurance.	Design Module 1
Number of Assembly Stations	The team cannot add more assembly stations.	Design Module 1
Number of machines in SPD	Machines are large and expensive, so it is not within the scope or possible to add any more.	Design Module 2
Shift duration of workers	This is set by the hospital and cannot be changed due to OSHA violations.	Design Module 2
Processing times of machines	The processing times of the decontamination washers and sterilizers are constant and must not change to comply with AAMI and IFU guidelines.	Design Module 2
Capacity of machines	The capacity of a machine is fixed, as each machine can only fit a certain number of trays. Each decontamination washer can fit 6 trays, while each steam sterilizer can fit 15 trays.	Design Module 2
Space constraints	The SPD has recently been renovated, and the team cannot expand the space. The current space and layout follow FGI guidelines.	Design Module 2
Fixed costs with adding trays	If the simulation model dictates the necessity of additional trays, there is a fixed cost associated with ordering new trays.	Design Module 2

Appendix E: Tray Defect Analysis Process

To find and categorize all SPD delays, team members went through the list of all delayed surgeries in 2021 and 2022, and manually labeled them as one of six categories: Broken/Damaged Instruments, Case Cart/Trays not Ready, Contaminated Instruments, Missing/Wrong Instruments, Other SPD Defects, and Not Related to SPD. Team members did so by referring to the comments left by Operating Room staff on the reason for the delay. While doing this, team members also disregarded surgeries that had no comments attached as to avoid inflating the number of SPD delays.

Appendix F: Design Alternatives for Quality Assurance Measures

	Design Alternatives		
	Design Alternative 1 Using the weight of each tray to implement mistake-proofing for missing/wrong instruments	**Design Alternative 2** Implementing a Quality Audit Station after Assembly	**Design Alternative 3** Adding images for all instruments and instrument substitutes into SPM
Performance Objective	Reduce the number of missing and wrong instruments	Reduce the number of all tray defects (e.g., missing instruments, contaminated instruments, etc.)	Reduce the number of missing and wrong instruments
Resource Constraint	PAH would need to purchase weight scales for each assembly station. In addition, they would need to standardize the weight of trays and add this constraint to SPM.	There is a lack of technicians to add another station with no space to repurpose into a quality audit station.	PAH would need to input images of all instruments purchased into SPM.
Time Constraint	There are too many kinds of trays to weigh all of them.	This may increase processing time at assembly station	There are numerous instruments, so it would be a time-consuming process.

Other	Many instruments might have similar weights, leading to indistinguishability.		The instrument substitutes vary based on surgeon and cases.

Appendix G: Quality Audit Checklist

Instrument Check: Conducted by SPD Supervisor or SPD Lead

Date: ______________________________
Supervisor/Lead Name: ______________________________
Instrument Technician Name: ______________________________
Tray Name: ______________________________

External Quality Audit Checklist

Does the tray have a barcode?	Yes	No
Is the tray in good operating condition?	Yes	No
Is the sterilization wrap free of holes and tears?	Yes	No
Is the sterile lock attached and locked properly?	Yes	No
Is there a load card present?	Yes	No

Internal Quality Audit Inspection

Is the biological/chemical indicator present in the tray?	Yes	No
If a sterilization container is used is the filter properly placed in the tray?	Yes	No
Is the count sheet present in the tray?	Yes	No
Is the count sheet correct?	Yes	No
Are all instruments in the set functional?	Yes	No
Does the tray have the correct number of instruments based on the tray count sheet?	Yes	No
Are all instruments visually clean?	Yes	No

Are appropriate items disassembled correctly?	Yes	No
Is the chemical indicator placed in the correct location?	Yes	No
Is there foreign objects in the tray?	Yes	No
Is there moisture present in the instrument tray?	Yes	No

Action Taken by Supervisor

Appendix H: Survey for Technicians

Are you an Agency worker*?

- Yes
- No

What is your level of experience? (How many years have you been an instrument technician?)

- <1 year
- 1 year
- 2 years
- 3 years
- 3+ years

	1	2	3	4	Score
Workflow	The current assembly process has many interruptions, and the process is very time consuming	The current assembly process has interruptions, and the process is time consuming.	The current assembly process has few interruptions and is somewhat time consuming	The current assembly process has no interruptions and is not time consuming.	
Human Error	I am very likely	I am likely to	I am	I am not likely	

	to make mistakes when assembling a tray due to human error	make mistakes when assembling a tray due to human error.	somewhat likely to make mistakes when assembling a tray due to human error.	to make mistakes when assembling a tray due to human error.	
Accountability	I never double check my work to avoid mistakes when assembling a tray	I rarely double check my work to avoid mistakes when assembling a tray	I almost always double check my work to avoid mistakes when assembling a tray	I always double check my work to avoid mistakes when assembling a tray	
Satisfaction**	The quality audit checklist will provide a negative impact in terms of decreasing the number of tray defects.	The quality audit checklist will provide no impact in terms of decreasing the number of tray defects	The quality audit checklist will provide minimal impact in terms of decreasing the number of tray defects	The quality audit checklist will provide great impact in terms of decreasing the number of tray defects	

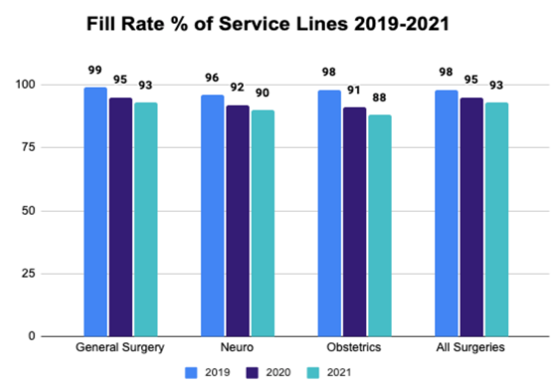
*An agency worker is a worker who is not directly hired by Piedmont but rather through third-party agencies.
**Only used in the post-implementation survey

Appendix I: Quality Assurance Checklist Recommendations

Due to current staffing levels, PAH implemented the pilot run with 15 checks per day. Since ISO 2859 prescribes 50 random checks per day, PAH should increase their number of checks to have a higher impact on the reduction of tray defects, when it is sustainable to do so. In addition, after gathering enough data on their quality checks, PAH could periodically identify which trays or service lines have higher numbers of tray defects. With this information, PAH could then target their quality checks at these identified trays or service lines.

Appendix J: Fill Rate for Overall and Most Profitable Service Lines

Three of the most profitable service lines at Piedmont Atlanta Hospital are General, Neuro, and Obstetrics. The team analyzed the fill rates for these three service lines to look at the number of surgery delays and tray availability. The team also looked at the overall fill rate for all service lines.



Appendix K: Design Alternatives for SPD Resource Improvements

	Design Alternatives			
	Design Alternative 1 Tray prioritization forecasting tool	**Design Alternative 2** Tray optimization per service line	**Design Alternative 3**: Instrument and peel pack inventory system	**Design Alternative 4:** Modified surgery scheduling process
Performance Objective	Forecast the processing order of various tray types	Reduce the number of instruments within each tray of a particular service line	Determine the optimal order quantities, reorder points, or safety stock levels for all instruments	Maximize the use of ORs while not overwhelming SPD with nonstop arrival of trays
Cost Constraint		Incurred holding cost for unused instruments	Increased purchasing and holding costs	Unused OR incurs an opportunity cost

Resource Constraint	There is insufficient buffer capacity to store unprioritized trays.	Removed instruments will need to be reallocated.	Storage will need to be available for the extra instruments.	Current OR capacity is 60% and SPD labor fluctuates per shift.
Time Constraint	All trays entering SPD are expected to be decontaminated within an hour of arriving.	Processing time at the Assembly station would be reduced.	Delivering the instruments has a lead time that could fluctuate seasonally.	Scheduled surgeries are currently not being performed on weekends and past 5pm on weekdays.
Other		All surgeons using a tray must agree on the modifications to it.	The highly variable demand of surgeries affects instrument need.	Emergent and urgent surgeries would need to be accounted for.

Appendix L: Data for Design Module 2

Table L1. Source and Type of Data Collected

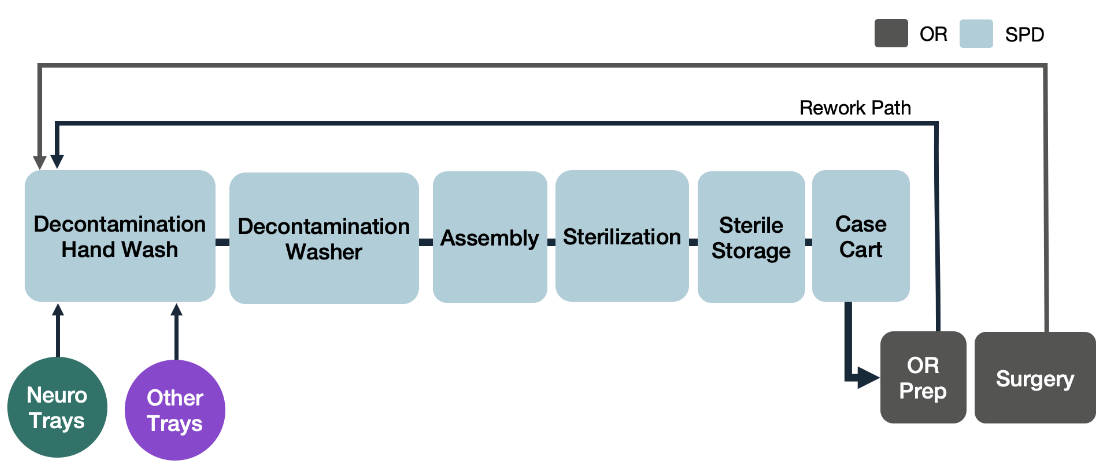
Source	Data
SPM Database	Time stamps for trays processed at each SPD station in 2021
	Instruments required for each tray type
	Fixed processing times at Decontamination Hand Wash and Assembly
EPIC Database	OR surgery delays from 2019-2021with surgery name, start and end times, & delay reason
	Total number of surgeries performed per service line from 2019 to 2021
	Surgeon preference cards listing all the trays requested by each surgeon for a given surgery
	OR surgery schedule for 2021

SPD Management	Labor schedule with number of technicians per shift
Finance	Labor cost of instrument technicians in 2021
Online Market Value	Purchasing cost of trays

Using data on surgeon preference cards, types of surgeries performed, and count sheets, the team created a comprehensive glossary. This provides a breakdown of surgery type to the trays they make up and the instruments that make up those trays. Furthermore, the time stamp data shows the times at which each tray is scanned at each function of SPD in 2021. The team used the time stamps to calculate the tray processing times at each of the stations, while OR surgery duration data was used to compute inter-departure times to represent the interarrival times into SPD. Additionally, because the team did not have financial data from the client on tray purchasing costs, the team used market prices of the top 50 most used neuro trays to determine their respective purchasing costs. Labor cost information from 2021 on instrument technicians was provided by the Finance department, while the labor schedule data was obtained from SPD management that consisted of the number of technicians per SPD station at each shift.

Appendix M: Design Module 2 Simulation Details

The figure below shows the framework for the simulation model. There are two types of entities that represent neuro trays and trays of all other service lines. The rework path represents trays that must be returned to SPD for reprocessing if they are found with defects or missing instruments in the OR prior to the start of a surgery.



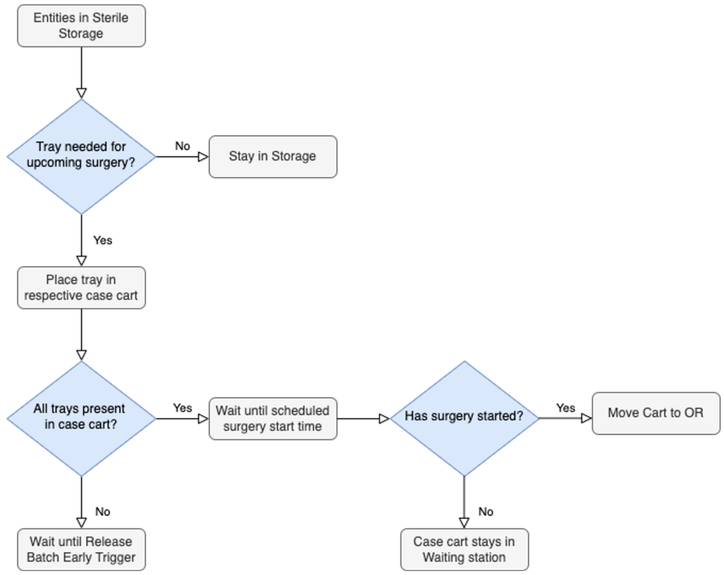
Simulation Implementation: Because it was difficult to replicate the exact locations of Neuro Trays in SPD at any particular time, all Neuro Trays were created at the start of the simulation run and were immediately sent to the Storage queue. Hence, to allow Neuro Trays to move throughout the system before statistics were collected, the run time included a warm-up period of seven days. The interarrival times of Other Trays, however, followed a lognormal distribution (Appendix __) determined by the inter-departure times of all non-neuro surgeries performed in 2021. Upon completion at Sterilization, the Other Trays exited the system as the scope for measuring tray availability and surgery delays was only on Neuro Trays.

Sterilization Batching: Because sterilizers can hold between 5 to 15 trays depending on tray size and the number of assembled trays, the model uses a Uniform (5,15) distribution to determine the batch size per load.

Dynamic Table: Preference cards are sent to SPD nine hours prior to a surgery's scheduled start time for case cart preparation. To account for this, the model updated an output table every five minutes that listed all surgeries that were fewer than nine hours away from their scheduled start time.

Case Cart Assembly: After Neuro Trays exited Sterilization, they were transferred to the Storage queue where they waited an indefinite amount of time. The model first checked the dynamic table for the tray preference cards of upcoming surgeries, and the trays in the storage queue were then cross-referenced with these preference cards. If there was a match, it transferred the tray(s) to the Case Cart Assembly station where they were then batched with case carts based on matching surgery IDs. In the case where all trays for a surgery were found in the queue, case carts were batched and immediately moved to the OR queue. However, if at least one tray was missing, the partially batched case cart waited a uniformly distributed time between 0 and 200 minutes before it moved to the OR. These distribution parameters were determined using the minimum and maximum delay times from the 2021 delay data.

OR Station: Every simulated minute, the model checked the OR queue and moved each case cart to the OR station at the assigned surgery start time.



Appendix N: Fixed Processing Times

Source	SPD Function	Processing Time
Steris Time-Studies Data	Decontamination Hand Wash	8.5 minutes
SPM Timestamp Data	Decontamination Washer	95.28 minutes
Steris Time-Studies Data	Assembly	17 minutes
SPM Timestamp Data	Sterilization	89.58 minutes

While the SPM timestamp data included tray waiting times which was unrepresentative of actual tray cycle times at Decontamination Hand Wash and Assembly, the team was able to use the SPM timestamp data for the tray processing times at the Decontamination washers and Sterilizers. Since instrument technicians scanned the trays only immediately before they entered the washers and after they completed the wash cycle, the time stamps did not include any waiting times.

Appendix O: SPD's Current Labor Allocation

Table O1: Average number of workers at the Decontamination Hand Wash and Assembly stations based on observations over the course of 2 weeks starting March 1st to March 15th.

Decontamination Hand Wash					Assembly				
Shift 1	Shift 2	Shift 3	Shift 4	Shift 5	Shift 1	Shift 2	Shift 3	Shift 4	Shift 5
3	2	2	2	2	8	8	8	8	8

Each instrument technician works either one of three weekday shifts (e.g., shifts 1-3) or one of two weekend shifts (shifts 4-5). Based on the time studies data collected by the team, these were determined to be the current labor levels SPD has at 60% OR capacity and were used in the simulation model to both validate the model and to compare with the optimal labor levels at Decontamination Hand Wash and Assembly.

Appendix P: Assumptions for Design Module 2

Data Cleaning Assumptions:

- **70% and 80% Capacity Schedule Assumptions:**
    - In 2021, the hospital operated at 60% capacity. To adjust the capacity to 70% and 80% for the future, the team made surgery schedules to simulate these increased capacity levels.
    - In the baseline model, there were 1764 neuro surgeries performed in 2021. This number was scaled to get the number of neurosurgeries performed at 70 and 80% OR capacity levels. At 70%, this was 1764 * 0.7/0.6 = 2059 and at 80%, this was 1764 * 0.8/0.6 = 2352.
    - To change the quantity of specific surgeries, the team found the quantity of each surgery scheduled in 2021 and multiplied each by the same factor as above and rounded to the nearest integer to get the desired quantity of 2059 and 2352.
    - To schedule these additional surgeries, the team took the additional number of surgeries needed to be added and divided that by the total number of hours in a year, which is 8760. For example, if 5 additional surgeries needed to be added to the OR schedule, then 8760/5 = 1752. This represents the number of hours in between each of the additional

surgeries. In other words, each surgery was scheduled to be 1752 hours apart from each other starting from January 1st to get the additional five surgery start dates and times.

- **Preference Card Assumptions:**
    - If a specific surgery for a surgeon did not have preference card data, the team used existing preference cards of other surgeons for the same surgery. The team looked at the surgeon who performed that surgery the most to use. If no preference cards existed for the same surgery, then the preference card of a similar surgery was used.
- **Cost Table Assumptions:**
    - Many trays contain many instruments, and the cost of each instrument was found manually by looking up each respective market value prices to determine the total tray purchasing cost
    - The team computed the tray purchasing costs for the top 50 most used neuro trays in 2021

Simulation Model Assumptions:

- Holding cost of trays is negligible since trays are reused
- All neuro trays are available in storage at the beginning of 2021
- Transit time of case carts to/from the OR and from/to SPD is negligible
- The procedure time of a surgery represents the length of stay of a case cart in the OR
- The inter-departure times between surgeries from the OR represent the interarrival time of case carts containing trays into SPD
- The time to pull trays from Storage and place them into case carts is negligible
- The earliest a case cart can be prepared is 9 hours before the scheduled start of the surgery
- No loaner trays are involved with the neurosurgery service line
- No emergency surgeries are accounted for in the model
- All trays take a similar amount of time to be decontaminated at both the sink stations and the washers
- All neurosurgery trays take a similar amount of time to be assembled
- Neurosurgery trays are only placed in steam sterilizers; no low-steam sterilizers are involved
- Decontamination and Sterilization machines run only when full capacity is reached
- Labor levels at each station per shift are the same every week

Appendix Q: OptQuest Fill Rate and Cost Equations

1. **Fill Rate and Total Cost:**

$$\text{Maximize Fill Rate} = \frac{N - D_s}{\text{N}}$$

$$\text{Minimize Total Cost} = P_c + L_c + D_c$$

$\text{N} = $ Total Number of Neuro Surgeries
$D_s = $ Number of Surgery Delays Due to SPD
$P_c = $ Purchasing Cost
$L_c = $ Labor Cost
$D_c = $ Delay Cost

2. **Delay Cost**

$$\sum_{i=1}^{n} D_i * \$301.94/\text{min}$$

$D_i = $ Length of delay of surgery i
$n = $ Total number of surgeries

3. **Labor Cost**

$$y_j * W_j * \sum_{k=1}^{q_1}(L_k * A_k) + z_j * W_j * \sum_{k=1}^{q_2}(M_k * B_k)$$

$A_k = $ Hours per weekday shift k
$B_k = $ Hours per weekend shift k
$W_j = $ Average hourly wage per bimonthly period j
$L_k = $ Total labor per weekday shift k
$M_k = $ Total labor per weekend shift k
$q_1 = $ Total number of weekday shifts
$q_2 = $ Total number of weekend shifts
$y_j = $ Number of weekdays in bimonthly period j
$z_j = $ Number of weekends in bimonthly period j

4. **Purchasing Cost**

$$\sum_{i=1}^{m} Y_i * T_i$$

$Y_i = $ Market value of tray type i
$T_i = $ Number of tray i purchased
$m = $ Total number of unique trays

Appendix R: OptQuest Constraint Decisions

Constraints were imposed on the decision variables by analyzing the tray purchasing costs to determine realistic lower and upper bounds on tray levels. The lower bound was set to the current number of neuro trays in SPD, while the upper bound for 60% OR capacity was set to the lower bound plus five. For a capacity of 70% and 80%, the upper bounds on the number of trays added to SPD for each tray type were lower bound plus seven and nine, respectively. Regarding labor, the lower and upper bounds were determined based on the maximum capacities for each station. For Decontamination Hand Wash this was

1 and 4, while the lower bound for Assembly at all three capacity levels was four with the upper bounds for 60%, 70%, and 80% capacities being 8, 10, and 12, respectively.

Appendix S: ExpertFit Distribution Recommendations

Table S1: SPD Processing Times Distributions

SPD Function	Variance	Recommended Distribution	Parameters
Assembly Processing Time	60,810.45379	Log-Logistic	Location: 0 Scale: 219.58024 Shape: 2.11699
DHW Processing Time	26,978.72177	Beta	Lower endpoint: 0.01314 Upper endpoint: 2,849.09204 Shape #1: 0.47865 Shape #2: 12.27174
Storage Processing Time	4,999,700	Johnson SB	Lower endpoint: 0.00575 Upper endpoint: 130,130.306 Shape #1: 2.94177 Shape #2: 0.668
Neurosurgery Inter-departure Time / SPD Interarrival Time	241,799.37707	Lognormal	Location: 0 Scale: 106.25839 Shape: 1.48943

The time stamp data that was used to compute these distributions included waiting times, and the variance for the processing time at each SPD function was extremely high. Therefore, using either the empirical distribution or the recommended distribution listed in the table would have inflated the number of delays. Therefore, given the conditions of the data provided, the team decided to use fixed processing times as shown in Appendix L.

Appendix T: Simulation Model Validation

For the bimonthly periods, January-February and May-June, the team ran the model for 207 and 29 replications, respectively. The confidence interval precision formula was used to compute the minimum number of replications, as shown below:

1. January-February

$$\hat{n} = \left\lceil n_0 \left(\frac{\frac{H(n_o,\alpha)}{|\bar{Y_n}|}}{R^*} \right)^2 \right\rceil = \left\lceil 100 \left(\frac{\frac{1.818}{8.43}}{0.15} \right)^2 \right\rceil = 207$$

2. May-June

$$\hat{n} = \left\lceil n_o \left(\frac{\frac{H(n_o,\alpha)}{|\bar{Y_n}|}}{R^*} \right)^2 \right\rceil = \left\lceil 25 \left(\frac{\frac{4.85}{30.24}}{0.15} \right)^2 \right\rceil = 29$$

$\hat{n}$ = estimate of required total sample size

n_o = initial sample size

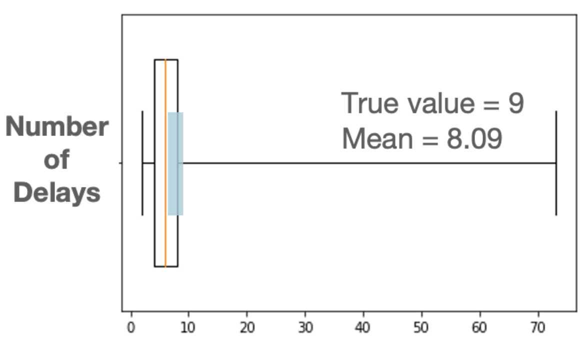
$H(n_o, \alpha)$ = half-length

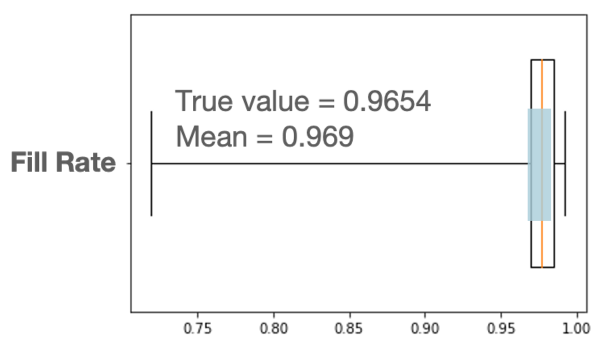
$|\bar{Y_n}|$ = point estimate

R* = relative precision

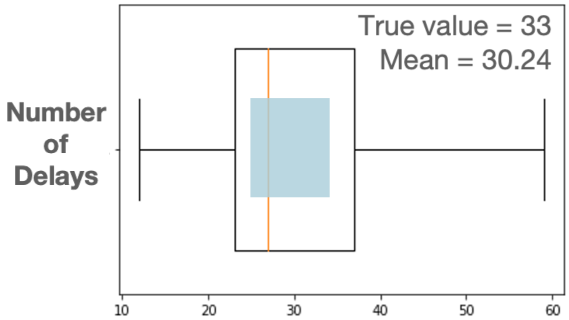
Below are the box and whisker plots on the number of delays and fill rate for each bimonthly period:

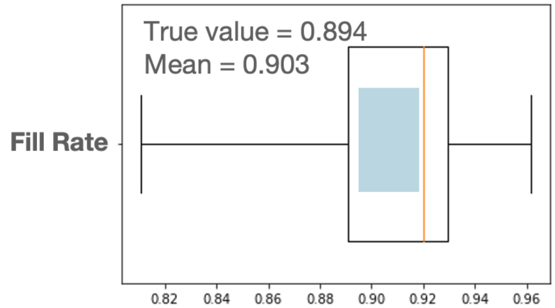
1. January-February





2. May-June





Appendix U: OptQuest Results and Recommendations for Model at 70% and 80% Capacity Levels

1. **OptQuest Results:** Analyzing the optimal results of the 70% model, there was a 28.1% increase in tray levels, where the recommended quantity for each tray type increased by two from the current levels. The optimal tray and labor levels also resulted in no delays with a fill rate of 100%. Regarding the 80% model, the total number of trays increased by 28.7%, and the achieved fill rate was approximately 99.8% with the recommended addition of trays ranging from 2 to 3.

   Similar to the results of the baseline model, the labor levels at Decontamination Hand Wash for the model at both 70% and 80% capacity levels increased by one or remained the same depending on the shift. Hence, the recommended number of technicians at Decontamination Hand Wash ranged from 2 to 3. At 70% capacity, the number of technicians at Assembly for all shifts decreased by two, while it decreased by one at 80% capacity. In other words, Assembly requires six technicians for all shifts at 70% capacity, and seven technicians must be allocated to this station for shifts when capacity is at 80%.

2. **Recommendations:** Similar to the recommendations for the baseline model, SPD should continue to reallocate their labor from Assembly to Decontamination once the hospital begins to increase their OR capacity. Additionally, as seen in the OptQuest results, increased tray levels are necessary for higher OR capacities.

Appendix V: Simulation Model Evaluation and Sources of Variation

One of the model's strengths is that it incorporates most of the high-level details of the SPD system by using an accurate OR schedule and implementing realistic processes for sterilization and case cart batching. Furthermore, this model can be easily implemented for other years and service lines to find optimal resource levels. However, another weakness is that the team did not have a comprehensive list of surgeon preference cards and made assumptions on the trays used for certain surgeries based on existing preference cards.

System Variability: Given the nature of the industry, emergencies and other events are unpredictable which led to variability in hospital and SPD operations. Related to this, Sterilization batching can oftentimes be reduced to fewer trays if surgeries need to be prioritized and the opposite can also be true.

Technician Variability: The team identified tray processing times by technicians and durations of different procedures as sources of variation within SPD. The variability caused by the former is due to the different levels of work experience and worker productivity while the variability of the latter is due to the nature of the different procedures. Due to national issues regarding instrument technicians, staffing levels have been fluctuating over these past years, hence it was difficult to identify trends in worker experience and productivity.

Appendix W: Excel Dashboard

The dashboard contains the following tables: (1) Metrics, which shows the fill rate and different types of costs for each capacity level; (2) Labor Allocation, which displays the optimal number of workers at Decontamination Hand Wash and Assembly at each shift; and (3) Tray Quantities, which shows the optimal tray quantities for each tray type

(1)

Metric	Value	Capacity
Fill Rate	99.84%	60
Total Cost	$1,182,202.06	60
Labor Cost	$911,593.44	60
Purchasing Cost	$268,495.00	60
Delay Cost	$2,113.62	60
Fill Rate	100%	70
Total Cost	$1,448,584.44	70
Labor Cost	$911,593.44	70
Purchasing Cost	$536,991.00	70
Delay Cost	$0.00	70
Fill Rate	99.78%	80
Total Cost	$1,660,550.60	80
Labor Cost	$1,012,881.60	80
Purchasing Cost	$555,275.00	80
Delay Cost	$92,394.00	80

(2)

Labor	Number of Workers	Capacity
Labor at Decontam Handwash Shift 1	3	60
Labor at Decontam Handwash Shift 2	3	60
Labor at Decontam Handwash Shift 3	3	60
Labor at Decontam Handwash Shift AM	3	60
Labor at Decontam Handwash Shift PM	3	60
Labor at Assembly Shift 1	6	60
Labor at Assembly Shift 2	6	60
Labor at Assembly Shift 3	6	60
Labor at Assembly Shift AM	6	60
Labor at Assembly Shift PM	6	60
Labor at Decontam Handwash Shift 1	3	70
Labor at Decontam Handwash Shift 2	3	70
Labor at Decontam Handwash Shift 3	3	70
Labor at Decontam Handwash Shift AM	3	70
Labor at Decontam Handwash Shift PM	3	70
Labor at Assembly Shift 1	6	70
Labor at Assembly Shift 2	6	70
Labor at Assembly Shift 3	6	70
Labor at Assembly Shift AM	6	70
Labor at Assembly Shift PM	6	70
Labor at Decontam Handwash Shift 1	3	80
Labor at Decontam Handwash Shift 2	3	80
Labor at Decontam Handwash Shift 3	3	80
Labor at Decontam Handwash Shift AM	3	80
Labor at Decontam Handwash Shift PM	3	80
Labor at Assembly Shift 1	7	80
Labor at Assembly Shift 2	7	80
Labor at Assembly Shift 3	7	80
Labor at Assembly Shift AM	7	80
Labor at Assembly Shift PM	7	80

(3)

Tray Name	Number of Trays	Capacity
McCracken Pituitary Specials	6	60
Medtronic Stealth Cranial Set #1	6	60
Stryker Vari Speed Screwdriver	4	60
McCracken Crani Specials	5	60
Fukushima Suction Tip Set	6	60
Greenburg Retractor Set	4	60
Neuro Crani Tumor Forceps and Scissors	6	60
Stryker TPS Drill System	13	60
Neuro Crani Rhoton Microdissector	7	60
Stryker Universal Neuro Low Profile Set	5	60
Craniotomy Set	11	60
Yasargil Leyla Retractor	6	60
Stryker Sonopet	6	60
TRAY RETRACTOR LEYLA / BAR	7	60
Neuro Ultrasound Probe	5	60
Neuro Spine Set A	25	60

Appendix X: Calculation of the Value of a Minute in the OR

Girotto, Koltz, and Drugas (2010) reported the cost of a lost minute in the OR in 2007 as $100 per minute or $6,000 per hour. The PWC Health Research Institute provides values for the percent increases in healthcare costs from 2007 to 2022. By applying these increases to the previously calculated values, one arrives at a value of $18,116.49/hour or $301.94/minute.

Appendix Y: Calculation of the Value of the Quality Audit Deliverable

Referring to Appendix J for the value of a minute in the OR and using the average duration of an SPD defect related delay (22.165 minutes), the team calculated that the cost of an average SPD defect at Piedmont is approximately $6,692.544. With the prevention of 17 defects during the pilot period, this equals to 17*6,692.544 or $113,773.248 worth of value for the pilot period alone. Scaling this up to the next full year by multiplying by 12, the team gets an anticipated cost savings of $1,365,278.976 for the next 12 months.

Appendix Z: Resource Planning Model Financial Value Calculations

1. **Total Cost of Current Resource Allocation:** The team looked at the lowest fill rate and highest fill rate per bi-monthly period which were May-June and January-February, respectively. The following are the costs incurred by the current tray and labor levels at 60% capacity.

	January-February	May-June	Average Bi-Monthly Cost
Labor Cost	$172,611.32	$174,977.24	$173,794.28
Delay Cost	$220,158.00	$862,497.00	$541,237.50

Purchasing Cost: $0 - No trays are purchased since this is SPD's current resource allocation.

Current total annual cost = (Average bimonthly delay cost + Average bimonthly labor cost) * 6 + Purchasing cost = ($541,237.50 + $173,794.28) * 6 + 0 = **$4,290,190.68**

2. **Total Cost of Optimal Resource Allocation:** The following are the costs incurred by the optimal tray and labor levels at 60% capacity for the same two bimonthly periods.

	January-February	May-June	Average Bi-Monthly Cost
Labor Cost	$150,927.84	$152,936.64	$151,932.24
Delay Cost	$0	$704.53	$352.27

One-Time Purchasing Cost: $268,495.00

Optimal total annual cost = Average bimonthly delay cost + Average bimonthly labor cost) * 6 + Purchasing cost = ($352.27 + $151,932.24) * 6 + $268,495.00 = **$1,182,202.06**

3. **2021 Total Cost Savings**

Total annual savings = $4,290,190.68 - $1,182,202.06 = **$3,107,988.62**

4. **2022 Total Projected Cost Savings**

Projected annual savings = Total annual savings in 2021 * Projected increase in medical cost = $3,107,988.62 * 1.065 = **$3,310,007.88**