Mohs Turnaround Time Tracking:
Final Report

Biomedical Engineering Design 200 - 300
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Abstract

Mohs surgery is a dermographic procedure and point-of-care process that involves removing and analyzing cancerous skin lesions. The time to return a sample for analysis, turnaround time (TAT), is a direct measure of efficiency and accuracy used in many laboratories across the globe to maintain specimen processing standards. At the UW School of Public Health and Medicine, the Mohs Laboratory team was looking to improve their TAT system. The previous system used physical time cards to record important steps of site preparation and contained several issues, making it difficult to measure TAT accurately and reliably. In addition, there were no other solutions on the market to fit the lab's workflow. For these reasons, a scanner system was implemented to utilize the patient barcodes associated with each site. Three of the time stamps were logged in EPIC and the fourth scan was manually recorded. This data was manually deidentified, formatted into a Google Sheet, and analyzed with custom code through Google Collaboratory. The scanner system was tested against the time card system to ensure no significant difference in average processing time was observed. In addition, a survey was administered to the lab staff that had used both systems to gauge the improvements in integration, ease of use, congestion, and lack of technical difficulties. All tests showed that the scanner system improved upon the previous time card system. This system will allow for TAT standards to be established within the Mohs lab, improving patient care, clinician satisfaction, and hospital profitability.

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I.   Introduction

Turn Around Time (TAT) is a very important and prevalent aspect in modern point-of-care laboratories. It is commonly referred to as the interval of time between specimen intake by the laboratory and the reporting of results [1]. This interval is crucial during point-of-care (POC) procedures where patient intake and screening is performed during a single visit [2]. The advantages of POC tests are real-time diagnosis and care to patients due to the rapidity of results[2]. Common POC tests include HIV, TB, hematology, chemistry, and are being actively assisted by the National Health Laboratory Services to establish TAT standards [3]. Clinicians rely on TAT for POC laboratory tests to provide prompt care and accurate results to patients. Additionally, clinicians often view laboratories as a service provider, factoring in their wait time to provide the best possible care [4]. When TAT for a POC procedure is unknown, disagreements between clinicians and lab technicians increase, and it has been noted that over 80% of laboratories receive complaints about TAT [5]. This disjunction can lead to lower quality patient care through longer wait times, a domino effect impacting all aspects of a clinic or hospital.

The establishment of TAT systems in laboratories previously lacking standards has shown to drastically improve testing results and accuracy. In a study of the Clinical Biochemistry Laboratory of Dhulikhel Hospital-Kathmandu University Hospital, over 31.74% of samples were unreadable due the TAT being too fast [1]. To avoid this, laboratories can implement a TAT system to define standards of specimen analysis.

However, before applying any TAT system, there are some recommended guidelines to follow highlighted by R.C. Hawkins in his research *Laboratory Turnaround Times* [6]:

1. Choice of appropriate analytes for monitoring,

2. Clear definition of TAT in terms of start points and endpoints,

3. Clear definition of measures to be measured.

4. Clear definitions of acceptable and unacceptable performance based on clinical evidence, benchmarking data, and local expectations.

5. Establishment of a system for long term monitoring of performance using available data.

The Mohs Laboratory at the University of Wisconsin School of Public Health and Medicine wants to improve their TAT system to provide reliable standards for clinicians and patients. The Mohs laboratory is unique as their procedure analyzes cancerous skin lesions in a single visit, which has been observed to reduce cancer and rapidly progress treatment [7]. Creating a more time effective and accurate TAT system would allow the lab to get results to patients faster while maintaining result accuracy. Since Mohs surgery is typically a single visit, out-patient procedure, the lab would like to evaluate their time data in order to find ways to minimize the time between surgery and patients receiving their results.

Currently, the Mohs Laboratory is using a time card system to track their TAT. Various problems have arisen with their system, such as skipped timestamps, limited time card supply, and the need for manual data entry. These issues put this system out of the recommended guidelines, making it impractical for long term use. Another TAT system on the market is Sunquest Laboratory™ Specimen Management Routing and Tracking (SMART) system [8].

However, this is not applicable to the UW Hospital system due to their dependency on EPIC [9]. In conclusion, a more automated TAT system that utilizes the existing barcode on each tissue specimen is required to develop standards for the Mohs Laboratory.

II.   Background

Mohs Research

Mohs surgery is a procedure in which skin cancer is removed from the outer layer of the skin. At first, the surgeon will take a sample of the skin (called a site) which is taken by a lab technician and split up into smaller sections called specimens. These specimens are mapped using dye in order to locate which section of the site has skin cancer. The amount of specimens ranges on the size of the site, with each and every specimen being tested in order to figure out the depth of the cancerous lesion [10]. The first site's results determine if another sample is necessary. If the cancerous spot ends within the first site with every section being cleared, the surgery is done. However, if the cancer remains in any of the sections, the surgeon will go in and repeat the process until all of the cancer is cleared, as depicted in Figure 1 [11]. This process is fairly simple, with the procedure and analysis all happening within a single visit lasting a few hours.
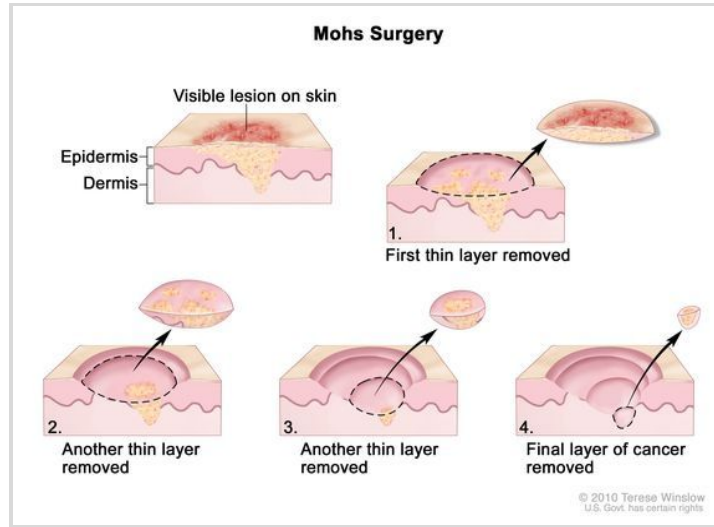
Figure 1: Example of the Mohs Surgery procedure with various extractions of the same site to remove cancerous layers. This is an iterative process that will create a unique timestamp in the laboratory for each layer. [11]
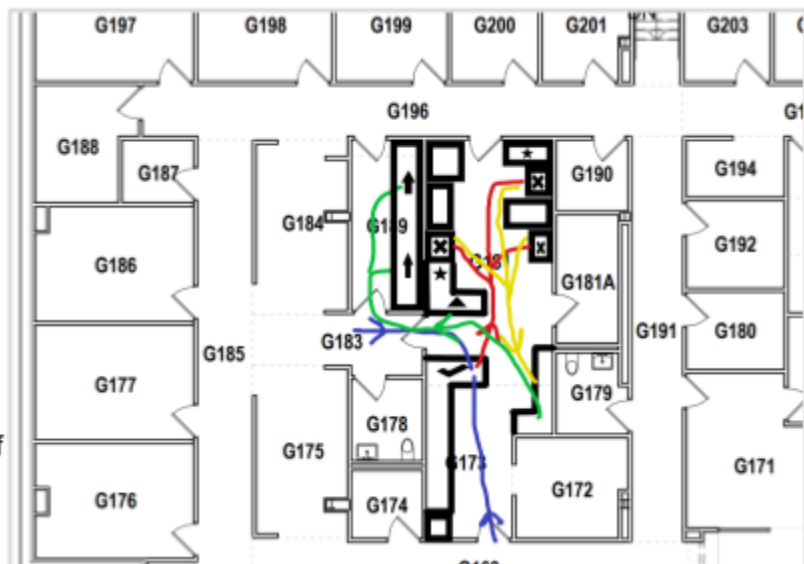
UW Hospital Lab Diagram

Figure 2: Layout of Current Lab at UW Hospital as depicted by Mr. Ryan Dauman. This map provides the basic workflow Mohs team members go through while processing a site. Colored lines are the movement of the specimen and the various shapes (defined in the key) represent important lab equipment and processing areas.

As most of Mohs surgery deals with the analysis of the tissue specimen, there is a lot of activity in the lab itself. Specifically, at UW Hospital they follow a path that includes three checkpoints within a small space. The first timestamp is when the physician delivers the specimen to the technicians and inks the specimen at the table marked with the checkmark [Figure 2]. The second timestamp is taken when the lab technician picks up and begins work on the specimen. During the time of analysis, the lab technicians take the path of the red and yellow lines, in which they inspect and cure the specimen at the tables designated by the X's [Figure 2].

Following the inspection and cutting of the specimen, the slide is cover-slipped and the third timestamp is recorded. Next, the slide is delivered to the physician, following the green arrow [Figure 2], to the microscope room where the specimen is inspected by the physician for cancer.

It is at this point the specimen is read and cleared by the physician for the procedure to be considered done. If the specimen is not considered clear (containing cancer), another stage will need to be taken and the process is repeated again, using another site from that same location. When the specimen is cleared, no matter the number of stages needed, the physician will declare the site is finished and signs it off at the last time point.

Client Information

The client is Mr. Ryan Dauman, a supervisor at UW Health who has been working with the lab technicians and the Mohs surgeon to find a time tracking system to measure TAT.

Design Specifications

The major design specifications for the new TAT system were to be efficient, accurate, and safe, all while remaining under budget. The Mohs lab is consistently processing sites and requires the system to be used daily Monday through Friday. Due to this schedule, a system needs to be created to differentiate between many test sites while causing minimal disruption to the workplace (Appendix A). Quantitatively, the system should cause no significant increase to the processing time for a sample, tested with a significance level of $\alpha=0.05$. Due to technology becoming ever more prevalent in medicine, the system needed to track all of its time points virtually, on the data program Google Sheets. Due to the use of Google Sheets and external systems, safety was required in regards to HIPAA compliance. The analysis must be able to show the average time per specimen, lab turnaround times, and any errors in scanning: all while maintaining HIPAA compliance.

Scanners brought into the lab added additional safety considerations such as being antimicrobial and having the ability to be sanitized. Additionally, the new technology brought concerns to shelf life, as needing to charge batteries or offloading data would require human intervention. For these reasons, the shelf life needed to last at least one week without outside assistance to ensure that the system will be up and running during the days the lab is open (Appendix A). These scanners were required to have Bluetooth connectivity to the lab computers at all times, no matter where the technician is within the lab, to prevent recording errors.

Finally, the system needed to be constructed for under $200, with the ability to utilize equipment and technology that already exists in the lab. Overall, the system for the UW Hospital

must provide a time tracking system with minimal disruption to the workflow. It should also be

able to provide accurate scans, without breaching patient confidentiality or contaminating the

specimen.

III. Preliminary Designs
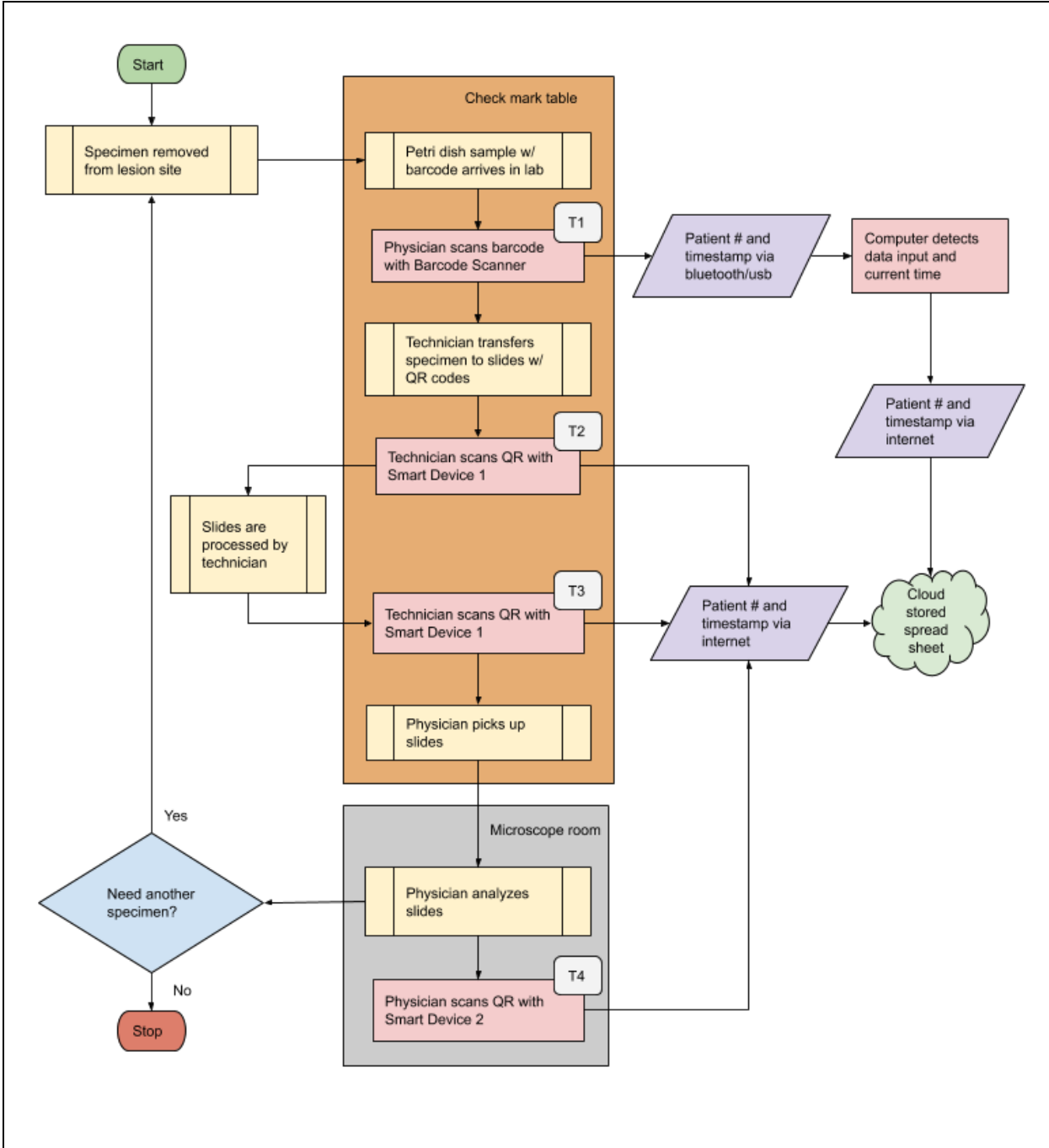
Figure 3. Flow diagram for the "Mixed" design. Note the two separate paths that data takes to the spreadsheet. T1, T2, T3 and T4 indicate the four times that the TAT system must track.

The Mixed design [Figure 3] involved the use of the existing barcode scanner in the lab. The scanner would have connected to a computer that uploaded patient identification and a timestamp to the cloud. For the remaining timestamps, smart devices would use a scanner app that could read QR codes and upload a timestamp and patient identification directly to the cloud. The Mixed design was estimated to increase the efficiency of the system, but has the potential to cause delays, while not as significant as the Smart design, due to the need for Wifi and Bluetooth connection.
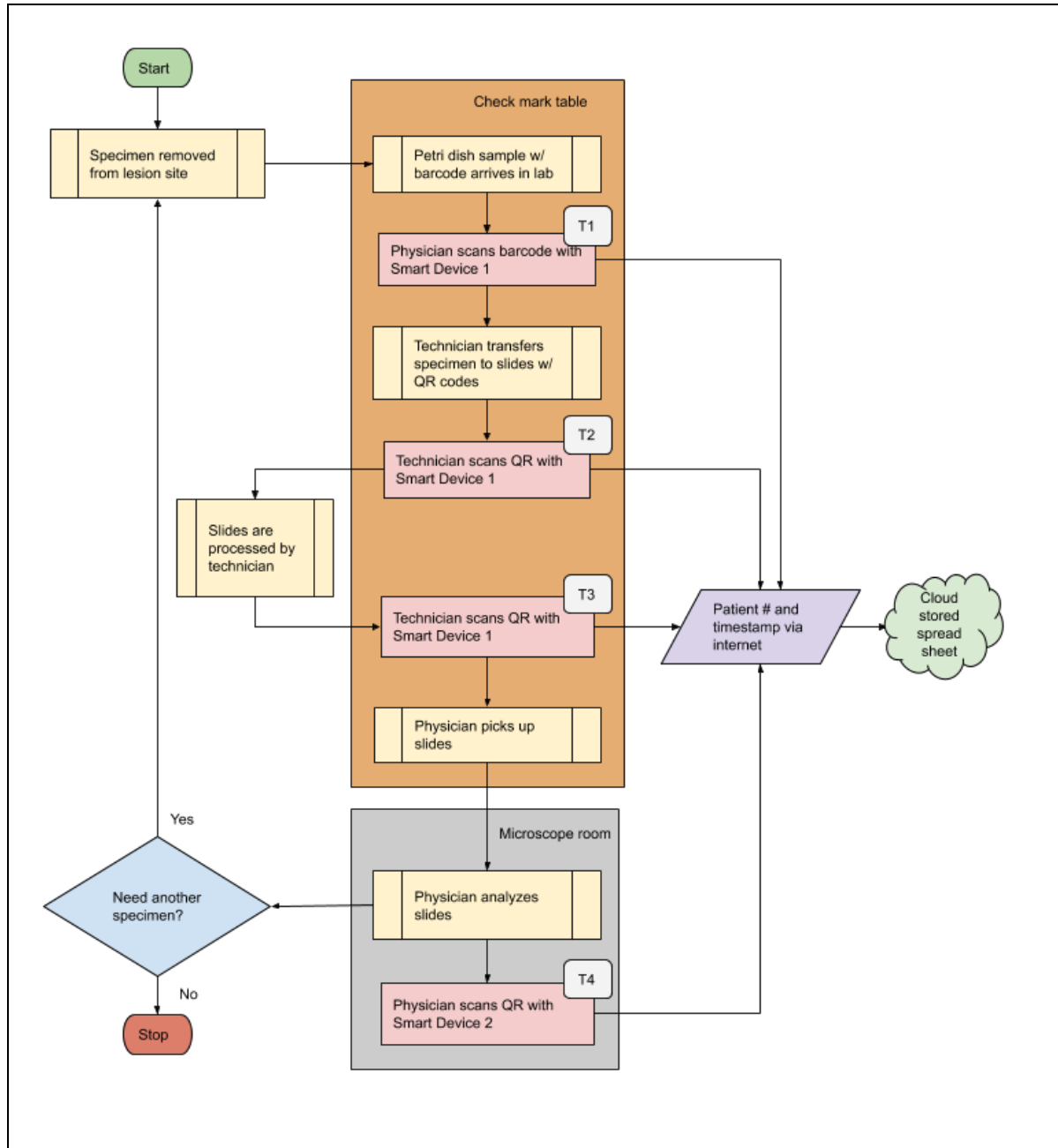
Figure 4. Flow diagram for the "Smart" design. Note how smart devices can directly transfer data to the cloud. T1, T2, T3 and T4 indicate the four times that the TAT system must track.

The Smart design [Figure 4] employed the use of just two smart devices, old phones or tablets. The devices would have used an app that scanned both barcodes and QR codes and uploaded this data to the cloud. The Smart design was estimated to have increased efficiency from the previous system, along with accuracy. However, issues could have arisen due to the

need for Wi-Fi and connection, which would have caused delays in the system if they are not
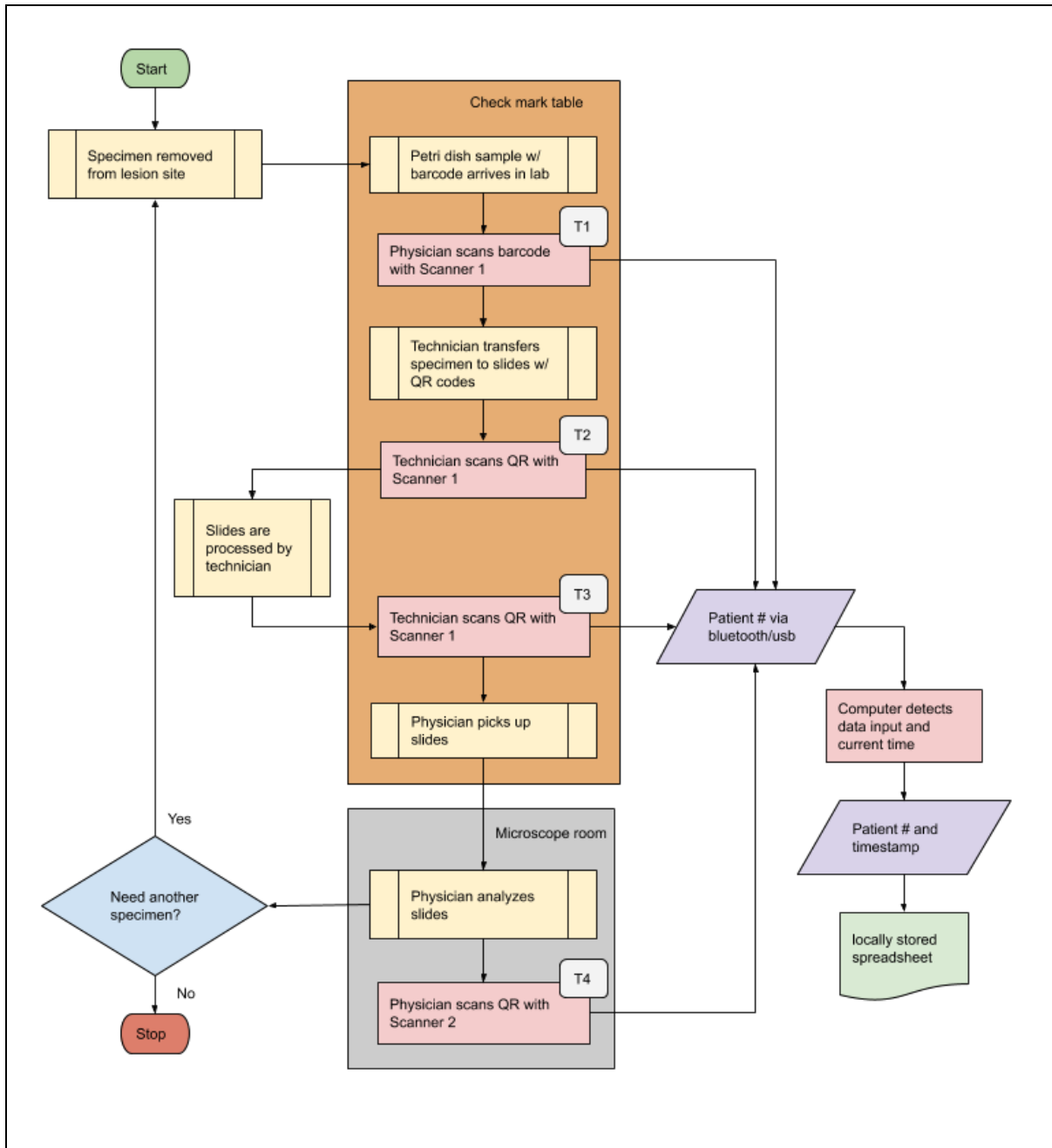
working properly.

Figure 5. Flow diagram for the "Scanner" design. Note the use of scanners at each step and the locally stored data. T1, T2, T3, and T4 indicate the four times that the TAT system must track.

The Scanner design [Figure 5] used two wireless scanners, the first of which can scan

both barcodes and QR codes, and the second which was the same kind of scanner but did not

need barcode capabilities. The barcode/QR data would have been transmitted via Bluetooth to a computer recording the patient identification as well as the current time into a spreadsheet. The Scanner design was estimated to be the most efficient of the three designs, given its lack of required Wi-Fi connection and ability to possibly transmit data via USB connection.

IV. Preliminary Design Evaluations

Criteria	Weighted Factor	Mixed	Weighted Score #1	Smart	Weighted Score #2	Scanner	Weighted Score #3
Efficiency	20.0	4.0	16.0	4.0	16.0	5.0	20.0
Accuracy	20.0	3.0	12.0	3.0	12.0	4.0	16.0
Ease of use	15.0	3.0	9.0	4.0	12.0	4.0	12.0
System Integration	15.0	3.0	9.0	4.0	12.0	4.0	12.0
Maintence Requirem	12.0	4.0	9.6	5.0	12.0	2.0	4.8
Safety	10.0	4.0	8.0	3.0	6.0	5.0	10.0
Cost	8.0	4.0	6.4	5.0	8.0	2.0	3.2
Total	100.0		63.6		70.0		74.8

Table 1: Design Matrix showing the evaluation of each preliminary design. Each of the seven categories were scored out of five, and then weighted with appropriate importance to the project and PDS.

1 - Efficiency

Efficiency was intended to evaluate the speed and possible congestion of workflow for each design. That is to say: Which design is the least likely to create delays in the laboratory? This was the most important criteria, as it was the determining factor in how quickly the patients get their results. By increasing the efficiency of the design, it minimized the time spent between

each step of processing the specimen. A high score in efficiency indicated that minimal time was spent by the physicians at each station for data entry.

Both the Mixed and Smart designs received 4/5 since they both involved having the first three time-stamp stations at the same spot in the lab, resulting in the possibility for crowding and traffic jams if all lab technicians needed to scan samples at the same time. The Scanner design rated a 5/5 because of the fact that it separated the location of the time-stamps in the lab more than the other two designs.

2 - Accuracy

Accuracy was intended to evaluate each design's ability to minimize human error (ie: skipping a step in the process). Additionally, it also evaluated a design's ability to accurately record the time-stamps in the tracking system. A high score in this category indicated that the design was both able to minimize the possibility for error and accurately records the time data.

The Mixed and Smart designs both received a 3/5 because they both relied on a smartphone or tablet at some point in the process, which are less reliable in terms of connectivity to wifi. The Scanner design was ranked a 5/5 because it did not have the need to be connected to wifi, which removed the chance of disconnection during work hours.

3 - Ease of Use

Ease of use was intended to evaluate each design's simplicity and how easily the lab staff is able to operate the system. A high rating in ease of use indicated an easy to use system that is not super complicated for the lab staff to use.

The Mixed design received a 3/5 in this category because it required the lab staff to become trained in using both scanner and smartphone technologies to operate the system. Both the Smart and Scanner designs received a 4/5 because they only required one type of technology, but both were different from the current system, so some training would be required.

4 - System Integration

System integration was intended to evaluate each design's ability to minimize additional clutter in the workspace and the amount of changes in the work environment required for the implementation of the system. A high score in this category reflected a design that does not take up a lot of counter space and one that did not drastically alter the workflow of the lab.

The Mixed design received a 3/5 in this category because of the complexity of two different technologies that required many changes to both the workspace and workflow of the lab. The Smart and Scanner designs received a 4/5 due to the fact that they required minimal counter space for implementation, but also required changes to the technology currently used in the lab.

5 - Maintenance Requirements

Maintenance requirements were intended to evaluate each design's need to be charged, updated, or repaired in order to maintain function and durability. A high score in maintenance requirements indicated a design's minimal need to be charged, updated, and repaired.

The Mixed design received a 4/5 due to its inclusion of a smartphone or tablet, which had minimal charging and repair requirements. The Smart design scored a 5/5 in this category because it solely relied on smartphones or tablets, meaning that charging and repair requirements

were low. The Scanner design received a 2/5 because the wireless scanners needed to be charged much more frequently than smartphones/tablets or require the batteries to be changed.

6 - Safety

Safety was intended to evaluate each design's ability to minimize the amount of physical contact needed to operate the system in order to minimize possible contamination to the tissue samples. It also was intended to evaluate each design's safety in terms of HIPAA compliance, which assessed the risk level for compromised or leaked confidential patient information. A high ranking in this category reflects safety in contamination minimization and patient information leaks.

The Mixed design received a 4/5 in safety due to its use of a scanner, but also the need for a smartphone or tablet, which can be hacked for patient information. The Smart design received a 3/5 because it only involved smartphones or tablets, which require higher levels of contact and patient confidentiality concerns. The Scanner design received a 5/5 because it eliminates the need for contact and also most effectively minimizes the risk of patient information being compromised. All designs had an increased risk of a leak of confidential patient information, due to the fact that a Google Sheets spreadsheet was used outside of the lab's EPIC system.

7 - Cost

Cost was intended to evaluate each design's monetary requirements. A high score in the cost category indicated that a design had a low-cost requirement for implementation.

The Mixed design received a 4/5 because it combined the low cost of a smartphone/tablet with a slightly higher cost of a wireless scanner. The Smart design received a 5/5 because it was the cheapest of the three designs. The Scanner design received a 2/5 due to the fact that reliable, wireless scanners were quite expensive comparatively.

Proposed Final Design

Based on the team's evaluation of each of the three designs, the Scanner design was decided to be the best fit to move forward with the proposed final design. This design was rated the highest in the following categories: efficiency, system integration, and safety. The Scanner design was best able to be integrated into the existing system in the Mohs Lab, mainly due to the fact that it removed the need for the first three scans to be done at the same station in the lab that was associated with both the Mixed and Smart designs. Additionally, patient information would be the safest due to the absence of the tablet/smartphones. However, because of the use of a Google Sheets spreadsheet to store and analyze the data, patient information had the potential to be compromised due to the information existing outside of the lab's EPIC software.

V. Fabrication/Development Process

Materials

The materials for the design were required to be able to withstand laboratory conditions including sterilization. Materials chosen should have been durable and non-toxic. The scanner chosen by the client was the NuScan 3500TB, an antimicrobial scanner which was built for a lab setting, capable of scanning both barcodes and QR codes and was easily recharged with a

magnetic charging cable (Appendix B). To store the data, cloud storage was used. The client used Epic System's cloud storage for timestamp data in order to comply with HIPAA. The data was then de-identified and inputted into Google Sheets (which is not currently HIPAA compliant) for the team to use. To read and process the Google Sheets data, the Python programming language was used. In order to streamline development and use, the team developed and ran Python code through Google Collaboratory, a free platform for running Python code. While Google Collaboratory itself is not HIPAA compliant and therefore must be used only with de-identified data, the code can be repurposed for any other platform that can run Python and thus can eventually be used on non-deidentified data if the client chooses.

Methods

The creation of the final prototype was not as simple as moving forward with the scanner design. After presenting our design ideas to the client, he was very interested in the "Smart" design due to its simplicity. Our focus shifted over to researching apps that allowed phones and other devices to scan barcodes and QR codes. Unfortunately, the team later learned that using smartphones with patient data would potentially require encrypted devices. Therefore, the Scanner design was revisited since it does not involve storage of the data on the scanner. Next, the team obtained a barcode scanner to understand how it interfaced with the computer. The scanner needed to be factory reset and a carriage return suffix was added (Appendix F). Furthermore, since the scanner itself did not have a real-time clock (RTC) it did not report its own timestamps. Therefore, the spreadsheet that recorded the barcode data was also set up to record timestamps at each data entry. Based on the output of the scanner and time stamp entry,

Python code was developed to process this data. By the time all this was complete, the team learned that the data needed to be deidentified before being put into the spreadsheet since the barcodes encoded the patient's MRN. Because of this short notice, the team had to compromise and include a manual step to de-identify the data.

Final Prototype

The final design prototype involved a slight modification of the Scanner design outlined in the Preliminary Design Evaluation. The major changes of the design were the inclusion of a manual de-identification step, which involved transferring barcode data for the first three timestamps from the Epic Systems server to a spreadsheet [Figure 6]. Since scanners in the lab were already set up in the lab to scan to Epic, there was no need to do any set up of the scanners. The client consulted with the physicians to try to get them to record the fourth timestamp either by verbally reporting it to the technicians or scanning themselves, however, the physicians did not cooperate. In the end, the final timestamp was extracted from the times handwritten on the site "maps" which are filled out during inspection of the specimen at Timestamp 4 [Figure 6]. Overall, this was not the worst outcome since the physicians are very busy and may forget or run out of time to record the timestamps. Also if the reporting of the timestamp occurs some time after inspection of the slide, this is not an accurate representation of when the timestamp actually occurred.
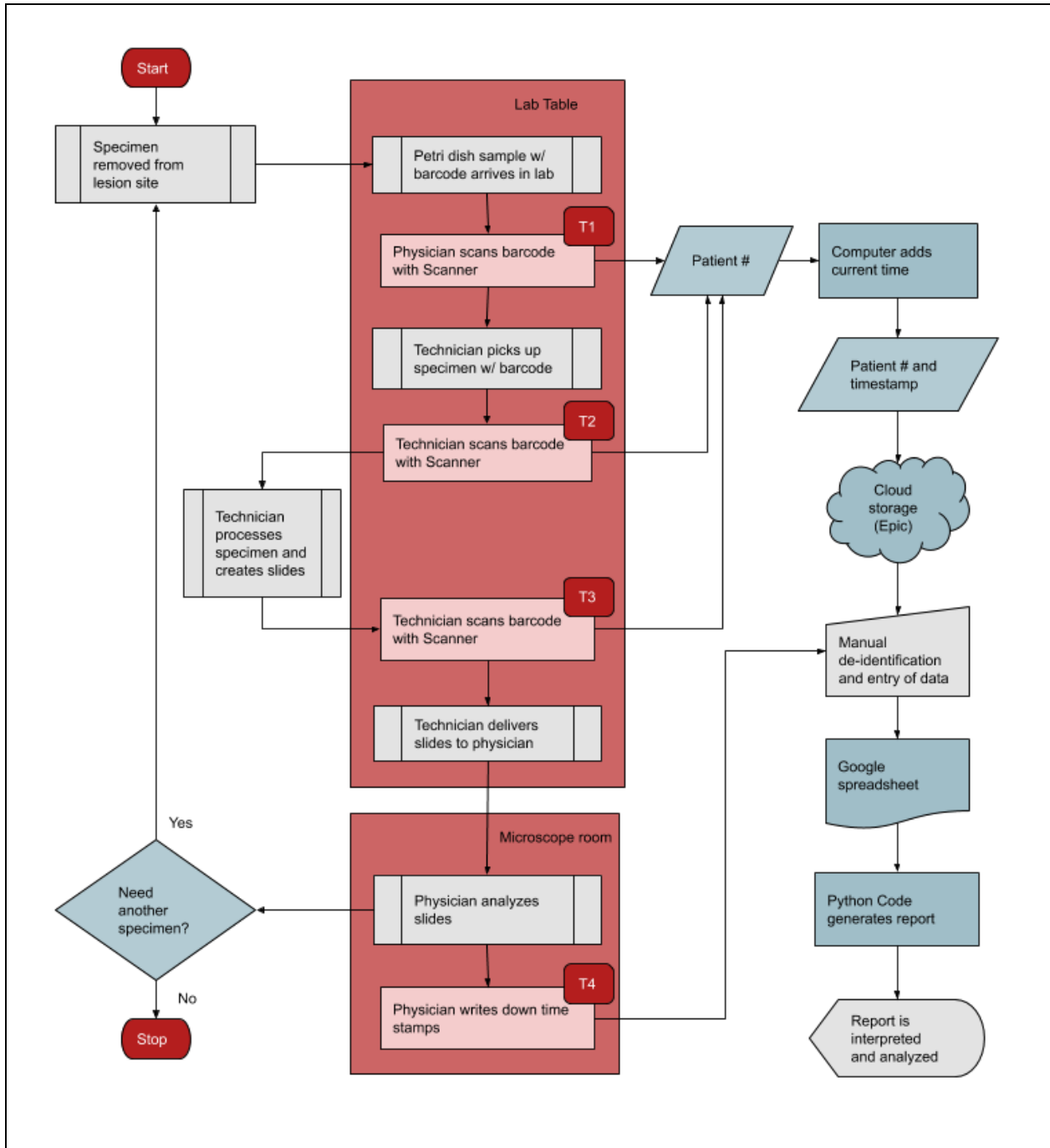
Figure 6: Flow diagram for the Final version of the "Scanner" design. Note that due to HIPAA restrictions, the data cannot be directly input to the cloud and must first be deidentified. Also, the physicians did not agree to use the scanner system so manual entry is required for T4.

Lastly, the final design included the data analysis process which was not included in the preliminary design evaluation due to it being ubiquitous of all design choices. The Python code in Google Collaboratory (Appendix C) is meant to be run every week to generate a weekly report that includes data, tables, and graphs generated from the de-identified timestamp data (Figure 7). Simple statistics were calculated and displayed as shown and outliers were reported with the intention of alerting the client of occasions where the turnaround time was significantly increased or decreased from normal. Furthermore incomplete data was reported to alert the client of erroneous data that was not recorded properly and thus could not be processed by our code.
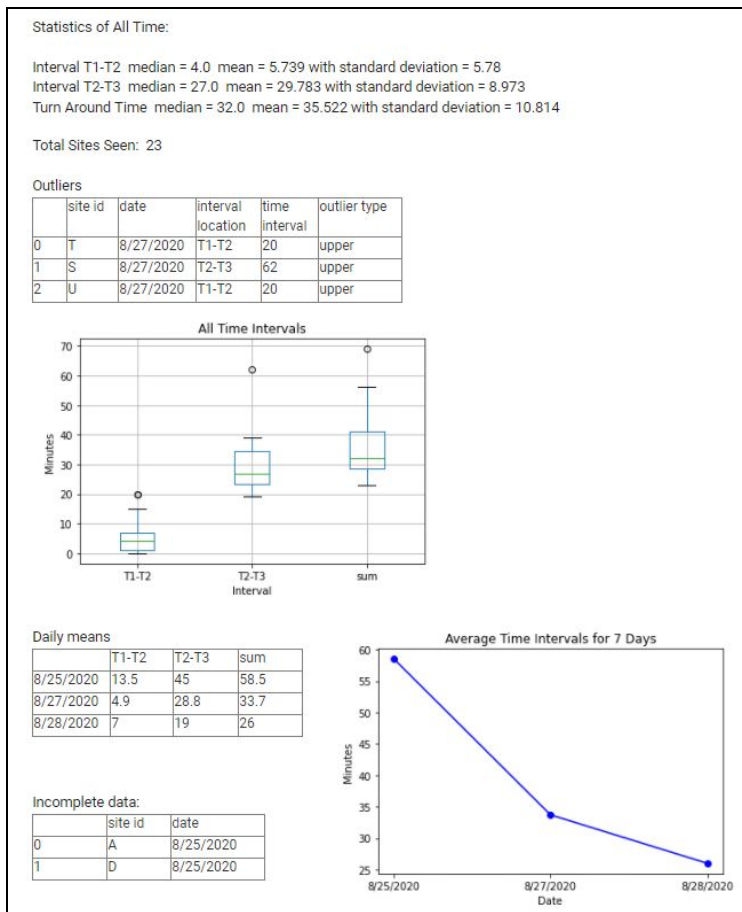

Figure 7: Sample output of the Python code using three days of timecard data. This timecard data output was compared to the scanner system output (see the Testing and Results sections below)

Testing

Testing was performed to ensure that the criteria outlined in the PDS were met. Quantitative metrics for indirect improvements on lab flow were needed regarding minimal disruption to the workplace and increased efficiency. Technician ease of use and integration into the workplace was also analyzed through a lab technician survey. Client specifications were qualitatively met in the final prototype. Finally, the analysis code went through several iterations to account for bugs.

To gain measures on disruption to the workplace and system efficiency, the time card system was compared to the scanner system. The client was able to provide three days of data from the time card system. Each of these time cards contained three timestamps per stage, excluding the final read time by the physician. The scanner system was implemented for three days and tracked the identical timestamps (including the read time by the physician, though it was excluded in this analysis). The data gathered was analyzed for significant differences between systems for their average time intervals. This proved that the scanner system was comparable to the time card system and did not cause significant disruption to the workflow. Efficiency could not be concluded in this test due to the nature of site analysis and the small sample size of three days.

To test the technician's ease of use, the team provided the laboratory with a Google Forms survey to gauge their opinions on both systems (Appendix E). This survey asked lab technicians to rate the time card system and scanner system back-to-back on several different criteria: integration into the workflow, ease of use, system efficiency (congestion at stamping

station), and lack of technical difficulties. Technicians who used both systems were asked to complete the survey. Each question was rated on a one to five scale, with one being the worst in that category and five being the best. The results of this survey showed the direct improvements made in regards to these criteria due to the scanner system.

The analysis code went through several iterations to account for bugs and errors. The most significant change was the adaptation from a hard-coded four timestamp analysis to an unlimited timestamp analysis. This alteration changed the framework of several functions, but in the end, resulted in an analysis flexible to any number of timestamps.

VI.   Results

A two-sample student's t-test was performed to analyze the mean times of the first (T1-T2), second (T2-T3), and site processing time (T1-T3) intervals for each system. In addition, an F-statistic was generated to validate the assumption of equal variances between samples needed to perform a two-sample student's t-test. The results are shown in the table 2.

	F-Statistic	p-value	T-statistic	p-value
T1-T2	0.6034	0.0860	0.7902	0.4313
T2-T3	1.1298	0.3349	0.5497	0.5837
T1-T3	0.9235	0.4313	0.5497	0.5837

Table 2: Test results of the F-statistic and the two-sample Student's t-test. Sample sizes of n=23 for the time card system and n=78 for the scanner system were used (All incomplete sites were excluded from data analysis in both samples, n=7). A significance value of α= 0.05 value was used to test for statistical significance in all hypotheses. All tests were performed in Matlab R2020 (Appendix D)

For all three intervals, the team failed to reject the null hypothesis, which indicated that there was no statistically significant difference between the mean times of both systems. This proved that the new scanner system implemented did not significantly increase the time required for processing. To better gauge the systems integration with the lab, a survey was conducted.

Survey results looked at the four main categories designated in table 3 below. In all categories, the scanner system was favored, indicating that PDS specifications were met in the final design.

	Time Card	Scanner
Integration into Workflow	2.33	3.67
Ease of Use	1.67	3.67
System Efficiency	3.33	4.33
Lack of Technical Difficulties	2.33	4.33
Overall Favorability	4.33	

Table 3: Results from the Mohs Lab technician survey (n=3). Each criterion was evaluated on a scale of 1 (worst) to 5 (best). Results were averaged in each section to determine how the technicians perceived each system. Note that overall favorability placed the time card system at 1 and the scanner system at 5.

Despite the number of survey responses being low, direct feedback from the technicians should not be discredited. The survey accepted written feedback on the scanner system and most responses requested additional scanners to be implemented.

The inherent design of the scanner system and materials used met many of the PDS criteria: wireless and portable, sterilizable and antimicrobial, less than 15 pounds, unlimited volume capacity (both simultaneous site tracking and overall iterations), completely virtual,

unlimited data storage, and implemented patient barcodes. However, due to time constraints, certain long-term criteria were unable to be fully tested: scanner charge life, the lifespan of the system, and continued weekly usage.

VII.   Discussion

As a result of implementing an accurate TAT system in the Mohs laboratory, the standards for TAT tracking have been met. The final prototype allows for a clear definition of starting and stopping points, the measures (intervals) being measured, and long-term monitoring of the lab's performance. Through continued use, the lab can define acceptable and unacceptable performance in benchmarking data and TAT expectations [6]. With a reliable system and guidelines established, there are many benefits the lab may experience in the near future.

The implementation of TAT systems in laboratories has a cascading effect that can improve all aspects of care. The first and foremost impact will be to develop standards for a TAT within tissue labs, as well as all types of healthcare settings that require a TAT system. These standards are primarily centered around how TAT allows the specimen to go through the lab faster. These shorter wait times decrease the patient's time in the hospital and allow the hospital to see more patients[12]. This is financially beneficial for the hospital itself, giving the lab the ability to see more patients, which in turn allows the lab to make more money. However, because of these rushed specimens, there must also be ethical considerations. One significant consideration comes from rushed specimens that could cause unanalyzable specimens, as noted in the Dhulikhel Hospital TAT study [1]. Another ethical consideration is the ability to focus on

patient care and site analysis, instead of rushing through specimen analysis. As a result of these considerations, a benchmark should be obtained from TAT averages to prevent rushed data while maintaining patient care.

After testing the TAT system in the Mohs lab, there were only a few changes that would be needed. From the feedback of the satisfaction survey, the major change required was the need for more scanners, including one for every technician and the physician. In data analysis, changes should be made in the code to catch accidental double scans by establishing a minimum time between scans to prevent this error. The other change comes from the HIPAA concerns. HIPAA is a major ethical consideration as it provides security to patient confidentiality and using the BAA agreement that Google provides, the lab would be able to use Google Sheet setup as proposed in the preliminary scanner design without breaches of patient confidentiality [13]. This would decrease the need for manual transferring of data and the likelihood of human error.

After testing the system, the major sources of error found to come from the code, sample size, and how BAA has not been put in place on the Google Sheet. Because of the small sample sizes from the satisfaction survey and TAT recorded, the data expressed in the testing results are not as accurate as it potentially could be. In the analysis code, there are a couple errors or situations that have not been accounted for due to limited testing in the lab. In particular, two repeated sites sequentially missing time stamps and accidentally double scanning a site need to be accounted for in future iterations of code. This source of error could be remedied or minimized if the system had more lab testing and more data to analyze. The final source of error comes from how the client had to manually enter the data into the Google Sheet because the BAA has not been signed and therefore the sheet is not in compliance with HIPAA. Overall, the

implementation of the new TAT system into the Mohs lab has been successful in setting standards for both care and time measurement.

VIII. Conclusion

The Mohs Laboratory was looking to improve upon their current TAT tracking system, a physical paper punch card system, and replace it with a more reliable, efficient, and accurate technology-integrated solution. The implementation of the scanner system effectively improved upon the time card system in all categories, as proven by our testing. One wireless scanner is currently being used to track the first three time stamps into EPIC with the fourth stamp being manually recorded. This data is pooled by hand, de-identified, and uploaded to the Google Sheet. Custom Python code running through Google Collaboratory provides data analysis of the timestamps and returns various averages, outliers, and charts. This code is flexible to as many timestamps as the lab would like to record and can catch incomplete data.

In the near future, having the hospital sign a BAA agreement to allow the use of PHI in Google Sheets would streamline the data analysis process. If this agreement can be completed, all timestamps would be automatically uploaded to and formatted properly in the Google Sheet, requiring close to no manual data entry (physicians timestamp is dependent). This would decrease the opportunity for human error as data is being formatted into the spreadsheet. In addition, integrating several scanners into the system as requested by the technicians would help streamline the process. This brings about complications with multiple simultaneous entries into the datasheet, which could be fixed through slight modifications in the code to pull data from

multiple sheets or pages. Finally, utilizing a QR code printer to easily label and scan slides from a site would help physicians perform the final scan.

In two to three years, the client expressed interest in fully integrating the system into EPIC to allow for further data to be collected. This EPIC based program would use the outlined structure and workflow created by the team to integrate more details behind time stamps, such as technician, site difficulty, and other information important to the laboratory. Due to the wide use of EPIC EMR systems throughout the U.S. and global hospitals, this system could be applied to laboratories globally. The impact of global laboratory TAT tracking would help develop standards for identical procedures, ensuring maximum patient care and hospital profitability.

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X. Appendices

Appendix A: **Project Design Specifications (PDS)**

Function:

The goal of this project is to modify and update the existing Turnaround Time Tracking system used in the Mohs surgery laboratory. Mohs surgery involves the removal of tissue specimens from the patient and subsequent laboratory work on each specimen. To ensure the quality and efficiency of this procedure, the laboratory has adopted a time tracking system. Currently, the physician or lab technicians are tasked with punching paper time cards at each transition in the laboratory process. Physical time cards are inefficient and may lead to misplaced or incomplete data. Thus the team is tasked with creating a more automated turnaround time tracking system that utilizes the existing barcode on each tissue specimen.

Client requirements:

- The timestamps that must be recorded are:
  - when the tissue specimen arrives at the lab
  - when a technician begins to work on the tissue specimen
  - when the finished slide is returned to the physician
  - when the slide has been read by the physician

- The barcode contains 2 patient identifiers and will be used to assign individual specimens to the time at which they were scanned at each stage. All of this information must be recorded on a computer in Google Sheets.

- The system must be able to handle cases in which a specimen needs additional work in the laboratory. Additional timestamps must be recorded.

- Eliminate human error from the system and minimize the manual work done to produce the timestamp data.

Design requirements:

1. Physical and Operational Characteristics

    a. *Performance requirements*:

        i. The system will be used every weekday, with busier days on Monday, Tuesday, and Thursday.

        ii. It should decrease turnaround times

        iii. It should decrease the frequency and severity of timing errors

    b. *Safety*:

        i. The barcodes used should be HIPAA compliant

        ii. The scanners used need to be antimicrobial and have the ability to be sanitized

        iii. General laboratory equipment safety requirements should be met

    c. *Accuracy and Reliability:*

i. The system should be able to record the time between each station to the nearest second for time less than 24 hours

ii. Should be able to differentiate between different sites being scanned

iii. Any scans need to be automatically uploaded to the Google Sheet

d. *Life in Service*:

i. The system should be able to track time upwards of 10 hours but not over 24 hours (sites enter the lab and are completed on the same day) of all active sites in the laboratory.

ii. The maximum anticipated volume is 20 sites per day, however, the system should be able to handle more if a site needs additional stages.

iii. The system must be able to handle upwards of five sites being continuously circulated through the lab.

e. *Shelf Life*:

i. System should last a minimum of 1 week without charging or the offloading of data

ii. The overall life span of the system should be upwards of 3 years

f. *Operating Environment*:

i. Cause minimal disruption to the workplace (no significant increase to processing time for sample $\alpha = .05$)

g. *Ergonomics*:

i. Lab physician and lab technicians must be able to use the system with relative ease

h. *Size*:

    i. Should be portable in order to be moved around the lab when needed

    ii. Involves the use of at least one scanner and one computer in the lab

    iii. The future possibility of obtaining up to six scanners in use at one time and getting a second computer in the lab

i. *Weight*:

    i. Should be no more than 15 lbs (tentative value) - must be able to be easily moved by lab members as needed

j. *Materials*:

    i. Products included in the system need to be sterilizable as they are a part of a laboratory and should be antimicrobial.

k. *Aesthetics, Appearance, and Finish*:

    i. No specific requirements for the appearance of the system have been identified

2. <u>Production Characteristics</u>

a. *Quantity*:

    i. One unit

b. *Target Product Cost*:

    i. The ideal budget is $200 with the ability to use already existing equipment in the lab with it.

3. <u>Miscellaneous:</u>

a. *Standards and Specifications*:

<ol type="i" start="1">
No FDA approval required, any uploading data must be HIPAA compliant and not breach patient confidentiality

<ol type="a" start="2">
Customer:
<ol type="i">
Digitize the system as much as possible
Maintain barcode/patient label system already in use

Patient-related concerns:
<ol type="i">
The data from the time tracking will have to be confidential as well as any patient information that goes along with it due to HIPAA.

Competition:
<ol type="i">
The current time card system at the Mohs lab
Sunquest Laboratory™ Specimen Management Routing and Tracking (SMART) system - this system could not work because of its inability to work in their EPIC system

Appendix B: **Materials Costs Table**

Item/Desc.	Mfr.	Part No. (ASIN)	Qty.	Price
Xenon 1900 - USB wired, healthcare 2D barcode scanner	Honeywell	B07MR5TCQ2	1	N/A*
NuScan 3500TB - bluetooth wireless, antimicrobial, waterproof 2D barcode scanner	Adesso	B07NBKT3NC	1	$150.02 (Amazon)

*The Xenon 1900 Scanner was already owned by the lab

Appendix C: **Mohs Lab Computer Code**

```
#required autentication
from google.colab import auth
auth.authenticate_user()
import gspread
from oauth2client.client import GoogleCredentials
gc = gspread.authorize(GoogleCredentials.get_application_default())

import pandas as pd
import matplotlib.pyplot as plt
import time
import datetime

#load data from google sheets
wb =
gc.open_by_url('https://docs.google.com/spreadsheets/d/1_yBW7Ru3XNIL9vjDs6FnFARy8Qn_Of
F6YqJxhpdbPuk/edit#gid=0')
sheet = wb.worksheet('data analysis')
data = sheet.get_all_values()
df = pd.DataFrame(data)
#add column headers
df.columns = df.iloc[0]
#remove document headers
df = df.iloc[1:]

site_id_head = df.columns[0]
time_stamp_head = df.columns[1]

NUM_TIME_STAMPS = 3
NUM_DAYS = 7

def get_unix_time(raw_time_string):
  #
  # gets unix time given a date string. milliseconds are ignored
  #
  time_string = raw_time_string.partition(".")[0]
  result = time.mktime(datetime.datetime.strptime(time_string, "%m/%d/%Y
%H:%M:%S").timetuple())
  return result

def get_unix_time_mins(raw_time_string):
  #
  # gets unix time given a date string. milliseconds are ignored
  #
  time_string = raw_time_string.partition(".")[0]
  result = time.mktime(datetime.datetime.strptime(time_string, "%m/%d/%Y
%H:%M:%S").timetuple())
  return result/60

# calculate unix time
unix_time = [get_unix_time_mins(time) for time in df[time_stamp_head]]

#create a new column for unix time or overwrite an old column of the same name
if "unix time" in df:
  df["unix time"] = unix_time
else:
  df.insert(1, "unix time", unix_time, True)
```

```
df = df.sort_values(by=["unix time"])

times = df["unix time"]
bucketed = []
incomplete = []
#iterate over unique patient ids
for id in set(df[site_id_head]):
  site_array = []
  #iterate over timestamps with that given id
  for time in times[df[site_id_head] == str(id)].values:
    site_array.append(time)
    #if  NUM_TIME_STAMPS timestamps have been added, append it and reset the
site_array
    if len(site_array) ==  NUM_TIME_STAMPS:
      bucketed.append((id,site_array))
      site_array = []
  #check if site array still contains elements. If so our data is incomplete and we
can report it as such
  if site_array:
    incomplete.append((id,site_array))

############################################################
#ALL TIME
print("\nStatistics of All Time:\n")

import statistics as stats
intervals_list = []
for id,timestamps in bucketed:
  #find the differences between each timestamp in seconds
  intervals = [j-i for i, j in zip(timestamps[:-1], timestamps[1:])]
  if any(interval for interval in intervals if interval < 0):
    print("Warning: negative interval calculated")
  intervals_list.append((id,intervals))

at_df = pd.DataFrame()
#at_df[site_id_head] = [id for id,intervals in intervals_list]

#column header strings
header = []
for i in range(NUM_TIME_STAMPS-1):
  label = "T"+str(i+1)+"-T"+str(i+2)
  header.append(label)

#now we want to analyze each interval in the time tracking scheme
each_step_at=[]
for i in range(NUM_TIME_STAMPS-1):
  #compile the time intervals for a given step
  step = [intervals[i] for id,intervals in intervals_list]
  #add this step information to dataframe
  at_df[header[i]]= step
  #record the mean and population standard deviation of each step
  each_step_at.append("Interval {}  median = {}  mean = {} with standard deviation =
{}".format(header[i], str(round(stats.median(step),3)),
str(round(stats.mean(step),3)), str(round(stats.pstdev(step), 3))))

for step in each_step_at:
  print(step)

turnaround_times = [sum(intervals) for id,intervals in intervals_list]

print("Turn Around Time  median = {}  mean = {} with standard deviation = {}".format(
```

```
        str(round(stats.median(turnaround_times),3)),
        str(round(stats.mean(turnaround_times),3)),
        str(round(stats.pstdev(turnaround_times), 3))))
print("\nTotal Sites Seen: ", len(intervals_list))
#find outliers

outliers_at= []
q1 = at_df.quantile(q=.25)
q3 = at_df.quantile(q=.75)
iqr = q3 - q1
upper = q3 + 1.5*iqr
lower = q1 - 1.5*iqr
for id,index in zip([id for id,intervals in
intervals_list],range(len(intervals_list))):
  for column in at_df.columns:
    if at_df[column].iloc[index-1] > upper[column]:
      outliers_at.append((id,df[df[site_id_head]== id]["time
stamp"].iloc[-1][:10].strip(" "),str(column),at_df[column].iloc[index-1], "upper"))
    if at_df[column].iloc[index-1] < lower[column]:
      outliers_at.append((id,df[df[site_id_head]== id]["time
stamp"].iloc[-1][:10].strip(" "),str(column),at_df[column].iloc[index-1], "lower"))

outliers_df_at=pd.DataFrame(columns= [site_id_head,"date","interval location", "time
interval", "outlier type"], data= outliers_at).sort_values("date")
print("\nOutliers")
display(outliers_df_at)

#Adding in sum column for TAT
copy_at_df= at_df.copy(deep=True)
copy_at_df["sum"]=copy_at_df.sum(1)

plt.figure(1)
boxplot = copy_at_df.boxplot(column=list(copy_at_df.columns))
plt.title("All Time Intervals")
plt.xlabel("Interval")
plt.ylabel("Minutes")
plt.show()

def get_date(raw_time_string):
  result = raw_time_string[:10].strip(" ")
  return result

#get date
date_i= [get_date(time) for time in df["time stamp"]]
if "date" in df:
  df["date"] = date_i
else:
  df.insert(1,'date', date_i, True)
  #Bucketing each site to it's respective day - TJ
dates = df["date"]
intervals_list
date_dict= {}
for site in intervals_list:
  x=df[df[site_id_head]==site[0]]
  day= x["date"].iloc[-1]
  #print(day)
  if day in date_dict.keys():
    date_dict[day.strip(" ")].append(site)
  else:
    date_dict[day.strip(" ")] = [site]
```

```python
#Bucketing each site to it's respective day - TJ
dates = df["date"]
intervals_list
date_dict= {}
for site in intervals_list:
  x=df[df[site_id_head]==site[0]]
  day= x["date"].iloc[-1]
  if day in date_dict.keys():
    date_dict[day.strip(" ")].append(site)
  else:
    date_dict[day.strip(" ")] = [site]


#ALL TIME DAILY AVERAGES
#Generate daily average stats- Table of Splits and TAT- TJ and Kevin

days= date_dict.keys()
average_daily_intervals = {}
for d in days:
  for interval in range(NUM_TIME_STAMPS-1):
    day_array = date_dict[d]
    if not d in average_daily_intervals.keys():
      average_daily_intervals[d] = []
    average_daily_intervals[d].append(stats.mean([site[1][interval] for site in
day_array]))

average_daily_intervals
avg_daily_int_df= pd.DataFrame.from_dict(average_daily_intervals, orient ='index',
columns= [header]).sort_index()
avg_daily_int_df["sum"]= avg_daily_int_df.sum(1)

print("\nDaily means")
display(avg_daily_int_df)

#this seems simpler to me just get the last 7 entries -KEVIN
n_day_averages =
avg_daily_int_df.iloc[max(0,len(avg_daily_int_df)-NUM_DAYS):len(avg_daily_int_df)]

# 3 # Plot of average interval time for most recent n days
x= list(n_day_averages.loc[:"sum"].index)
y_tat = n_day_averages[["sum"]]
plt.figure(2)
plt.scatter(x, y_tat, color="b")
plt.plot(x, y_tat, color="b")
plt.title("Average TAT for {} Days".format(NUM_DAYS))
plt.xlabel("Date")
plt.ylabel("Minutes")
plt.show()

# Incomplete time stamps - TJ and Kevin
incomplete_w_date= []
for site in incomplete:
  incomplete_w_date.append((site[0] , df[df[site_id_head]==
site[0]]["date"].iloc[-1]))
inc_df= pd.DataFrame(columns = [site_id_head, "date"], data=incomplete_w_date)
print("\nIncomplete data: ")
display(inc_df)
```

Appendix D: **Matlab R2020 Testing Code**

```
%% TAT 2 sample T-test analysis
T1 2 mean tc = 5.739;
T1 2 std dev tc= 5.78;
T2 3 mean tc= 29.783;
T2 3 std dev tc= 8.973;
tat mean tc = 35.522;
tat std dev tc = 10.814;
n tc= 23;
T1 2 mean scan = 4.577;
T1 2 std dev scan= 7.441;
T2 3 mean scan= 28.628;
T2 3 std dev scan= 8.442;
tat mean scan = T1 2 mean scan+T2 3 mean scan;    %compare processing time due
to lack of read in timecard info
tat std dev scan = sqrt(T1 2 std dev scan^2+T2 3 std dev scan^2);    %need to
do sum of variances to get std
n scan = 78;
%% T1-T2 analysis
f stat 12= (T1 2 std dev tc)^2/(T1 2 std dev scan)^2
f pval= fcdf(f stat 12,n tc,n scan) %assume that they are equal at alpha=
0.05 level, equal variances, accept H0
t val = (T1 2 mean tc - T1 2 mean scan)/sqrt((T1 2 std dev tc)^2/n tc +
(T1 2 std dev scan)^2/n scan)
p val= 1-tcdf(t val, n scan+n tc-2)+tcdf(-t val, n scan+n tc-2)
%% T2-T3 analysis
f stat 23= (T2 3 std dev tc)^2/(T2 3 std dev scan)^2
f pval= 1-fcdf(f stat 23,n tc,n scan) %assume that they are equal at alpha=
0.05 level, equal variances, accept H0
t val = (T2 3 mean tc - T2 3 mean scan)/sqrt((T2 3 std dev tc)^2/n tc +
(T2 3 std dev scan)^2/n scan)
p val= 1-tcdf(t val, n scan+n tc-2)+tcdf(-t val, n scan+n tc-2)
%% TAT analysis
f stat tat= (tat std dev tc)^2/(tat std dev scan)^2
f pval= fcdf(f stat tat,n tc,n scan) %CANNOT assume that they are equal at
alpha= 0.05 level, reject H0
t val = (T2 3 mean tc - T2 3 mean scan)/sqrt((T2 3 std dev tc)^2/n tc +
(T2 3 std dev scan)^2/n scan)
p_val= (1-tcdf(t_val,n_scan+n_tc-2 ))+tcdf(-t_val, n_scan+n_tc-2)
```

Appendix E: **Survey Questions/Results**

Survey Entry	Response 1	Response 2	Response 3	Average (5 = Best, 1 = Worst)
For those using scanners				
How well did the TIME CARD system integrate into your workflow?	2	3	2	2.33
How well did the SCANNER system integrate into your workflow?	3	4	4	3.67
How difficult was the TIME CARD system to learn?	1	1	3	1.67
How difficult was the SCANNER system to learn?	4	3	4	3.67
How congested was the TIME CARD station?	3	4	3	3.33
How congested was the SCANNER station?	5	5	3	4.33
Were there any technical problems when using the TIME CARD system?	2	3	2	2.33
Were there any technical problems when using the SCANNER?	3	4	3	3.33
Overall, how would you compare the two systems?	5	4	4	4.33
For those using the spreadsheet				
How readable and interpretable was the raw data presented in the spreadsheet?	5	N/A	N/A	5
How readable and interpretable were the data graphs and analysis presented in the spreadsheet?	3	N/A	N/A	3
How hard was it to enter data in the sheets?	5	N/A	N/A	5

Appendix F: **Procedure for Use**

Guide for using the Xenon 1900 scanner:

Scanning the following barcode resets the scanner to factory default

DEFOVR.
Restore Factory Defaults

In order to add a carriage return after each scan, scan the following:

PAP_AT.
IBM PC AT and Compatibles with CR suffix

These will re-program the scanner to default settings and add a carriage return (newline) as a suffix. This way the data will be added correctly to the spreadsheet.

Next, since the Honeywell Xenon scanners do not have an internal Real-Time Clock (RTC) A timestamp needed to be recorded in google sheets each time a new patient id was entered entering the following function into cell B1 (the top row and second column)

=IF(A1<>"", IF(B1="",NOW(),B1), "")

Then highlighting the entire A column and pressing ctrl+enter puts the function into every single column. What the function does is it enters a timestamp into the A column if a value gets entered into the B column and there isn't already a timestamp

Importantly: you must change file > settings > calculation to the following to allow iterative calculation:

Important notes about the code:

- The code is run in Google Collaboratory by pressing the play button on the upper left. Scroll down to see the results
- To alter the number of intervals change the # in "NUM_TIME_STAMPS = #" to the number of time stamps being taken
- To alter the number of days you want to review for daily averages change the # in "NUM_DAYS= #" to the number of wanted days

The code is pulling the data from the Google Sheets spreadsheet. Make sure the Google Sheet is formatted as follows (make sure you are using 24 hour time):

site id	timestamp
AAAA	MM/DD/YYYY HH:MM:SS
BBBB	MM/DD/YYYY HH:MM:SS

…

And so on

The code pulls from a designated tab in the google sheet. To change this in the code, look for:

sheet = wb.worksheet('data analysis')

To change tabs, rename 'data analysis' to the tab you want to analyze. The first and second columns in this sheet must follow the format as above.