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An Alternative Laboratory Information System (LIS) in Primary and Secondary Laboratories

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Abstract: Electronic Laboratory Information Systems (LIS) help in clinical laboratory workflow by providing several advantages over traditional paper-based methods such as accuracy in transmitting data and ease of access to patients' records that reduces the overall turnaround time (TAT). The rationale behind this study is to design and develop a cost efficient and effective alternative LIS that focuses on the pre-analytical and post-analytical accessioning and archiving of laboratory results with basic functions needed by primary and secondary laboratories. A survey was conducted to determine the preference of the respondents on LIS operations in terms of features that cover functionality, interface, patient records, results and reports viewing, and other additional features. Data from the said survey were collated and used as the basis for the features of the Raspberry Pi (RbP) LIS developed. The RbP LIS was pilot tested at two free-standing private laboratories to compare its use versus the traditional paper-based method. The results showed that for the pre-analytical testing, the use of RbP LIS had significantly shorter TAT compared to the paper-based method *($t= -14.25$, $p <0.001$)* with a mean procedure TAT of 13.85 minutes and 29.20 minutes, respectively. In terms of the post-analytical processing, the use of RbP LIS had significantly shorter TAT compared to the paper-based method *($t= -13.29$, $p <0.001$)* with a mean procedure TAT of 21.29 minutes and 39.36 minutes, respectively. A researcher-made 5-point Likert Scale survey was also used as an assessment tool to gather the insights of respondents about their experience in using the RbP LIS versus the traditional paper-based method in terms of accuracy, ease of accessioning, and ease of archiving. The results revealed that the respondents strongly agree that the use of RbP LIS allowed better accuracy, easier accessioning, and easier archiving in comparison to the paper-based method with a mean score of 4.62, 4.72, and 4.60, respectively. The researchers determined that RbP LIS outweighed the paper-based method based on the study's result. However, due to various restricting factors, it is suggested that the testing is done in more clinical laboratories and the survey questionnaire be deployed to more respondents. The RbP LIS program must also be tested for longer duration and simultaneously with the paper-based method in actual laboratory settings for more accurate comparison.

Keywords: Laboratory Information System, Raspberry Pi LIS, Accessioning

I. INTRODUCTION

There are three phases involved in the laboratory testing process. These are the Pre-Analytical phase, Analytical Phase and Post-Analytical Phase. The pre-analytical phase begins with the initiation of a test request up until the specimens are transported to their respective sections of the laboratory for analysis. The analytical phase is the second phase where the actual running of tests

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happens. The specimens will then be subjected to various laboratory instrumentation and automation. Lastly, the post-analytical phase includes the releasing, reporting, interpretation, storing and archiving of results. Out of the three phases in laboratory testing, most of the errors primarily come from the first phase which is the pre-analytical phase (Lukić, 2017). All phases of the laboratory testing have the capacity to produce errors since the phases are labor-intensive before the Laboratory Information System (LIS) was initiated. This requires manual encoding and record keeping of every patients' data such as patient identification, test requests and results which are time-consuming and costly. The implementation of LIS is a massive technological advancement for both hospitals and laboratories. This helps the procedures to become faster, reduce errors from each phase and improve health care delivery (Mtonga et al., 2019).

The Laboratory Information System (LIS) was first introduced in 1991 and 1998 in the Philippines. The plan of changing the old paper-based data collection system to a centralized digital data collection system was not pushed through due to an unsuccessful transition from a nationwide health sector to local health sector (Premji, Casebeer, and Scott, 2012). Research conducted from University of the Philippines-Manila created an electronic health information system called Community Health Information Tracking System (CHITS) in 2004 that could help the local and smaller health sector to give an evidence-based decision and diagnosis to patients (Tolentino et al, 2005: 312). University of the Philippines-Manila expanded the geographical coverage through their partnership with different provinces such as Quezon City, Navotas City, Pasay City, Loreto Dinagat Island, Leyte, Llanera and Nueva Ecija (Ongkeko et al., 2017). CHITS started its operation in 2 local health centers located in Manila (UP Manila - National Telehealth Center, 2010) and now CHITS is used by 171 local health centers across the country. Some rural health units are already experiencing significant improvements in their management operations but a lot of health centers in the Philippines are still employing labor-intensive processing. The project team is currently looking for investors to cover the initial capital to further expand the coverage of the technology. Investments from the venture capitalists will help them broaden their portfolio (Development Academy of the Philippines, 2020).

A standard computer is capable of doing programs with videos, documents and capable of being a server and so does the Raspberry Pi (RbP). It is a single board computer the size of a credit card. Basic computer tools can be hosted that can teach hosting servers, programming, and computing. There are five (5) current generations of Raspberry Pi. The first generation has only four models namely; A, A+, B, and B+. The present generation has only one model namely the Raspberry Pi 4 Model B. The latest model has a 4 GB Random Access Memory (RAM) and a 1.5GHz quad-core Broadcom BCM2711 64bit CPU. The enhancements are suitable for the large programs to process (Brodkin, 2012; Raspberry Pi 4 Model B+, n.d.; Raspberry Pi Model B, n.d.).

Changing the method of data collection in laboratories is expensive. The cost of LIS ranges from Php 200,000.00 to Php 5,000,000.00 which will vary depending on the complexity of the devices and features (Apex Healthware, n.d.). Investment and financing are significant for implementing or updating a LIS in a laboratory that is the reason a proposition must legitimize the expense and exhibits the estimation of it in a research facility so as to pick up endorsement for such a significant undertaking (Prasad & Bodhe, 2012). Large amounts of requirements are needed to be fulfilled

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and only established large hospitals and laboratories are capable of transitioning into fully automation. Despite the expected advantages in cost-effectiveness and patient care upgrades made possible with very much structured HIS/LIS, the vast majority of these frameworks linger altogether behind the potential outcomes managed by current data innovation (Sepulveda & Young, 2012). The dilemma is that the Philippines has a high poverty rate and has limited sources. Small and local laboratories and hospitals cannot adopt the new technology of LIS. The manual paper-based data collection systems still exist despite the advancement of hospital and laboratory technology in the country (Premji, Casebeer, and Scott, 2012). Progressively, the focal point of efforts to improve the quality of laboratory operations is in the analytical phase, which right now presents barely any issues, especially for those tests performed by exceptionally automated instruments. Improvement of quality is always focused on the analytical phase, but in reality, most errors come from the pre- and post-analytical phases of laboratory testing (Sepulveda & Young, 2012).

The researchers sought a way to solve the divide of automation among laboratories in the country. The general concept of laboratory information systems requires a server that will serve as a mainframe for the data to be received from the pre-analytical phase and sent out as a part of the post-analytical phase.

Research Problem

The study mainly aims to gather necessary information in designing an ideal Laboratory Information System (LIS) and to create a cost efficient and effective electronic LIS that focuses on the pre-analytical and post-analytical accessioning and archiving of laboratory results. It specifically aims to answer the following questions:

1. What is the level of preference of the respondents regarding LIS in terms of functionality, patient recording, results and reports viewing, and additional features?
2. Is there a significant difference between the turnaround time when using paper-based methods of accessioning compared to the proposed electronic LIS?
3. Is the proposed electronic LIS effective in terms of data accuracy, ease of accessioning and archiving compared to paper-based methods?

II. METHODOLOGY

Research Design

The study employed a Quasi-Experimental research design to determine the significant differences between the proposed electronic and traditional paper-based methods in the laboratory setting with regards to the pre-analytical and post-analytical phases of testing.

Subjects and Study Site

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The target population of the first phase of the study are Registered Medical Technologists that are currently working in Bulacan, Bataan, Paranaque City, Quezon Province, or Tuguegarao City. Furthermore, these licensed professionals must have experience of using LIS. Convenience sampling was utilized in the study since the researchers took advantage of their geographical locations during the implementation process as the basis of the study participants. The Rasoft Calculator was used to determine the recommended sample size needed for the survey conducted in phase one. According to the results of the Raosoft Calculator, a minimum of 105 respondents were needed for the study, and in the end, 109 respondents were obtained.

The laboratories which were eligible to partake in phase two of the study were ones categorized as primary or secondary. In addition, only those who employed manual logbook methods were eligible as subjects. Two (2) free-standing laboratories, namely the Tayabas Diagnostic Laboratory and Prolab Diagnostic, were chosen as subjects for the second phase of the study. The study took place from August 2020 to June 2021 and the testing was held in Tayabas City, Quezon Province.

Data Gathering Procedure and Instrumentation

The needed quantitative data for phase one of the study was obtained through a modified Laboratory Information Functionality Assessment Toolkit (LIS-FAT). As for the recruitment process, the researchers had contact persons in the laboratories in their respective localities who helped them control the dissemination of the survey, which resulted in a total of 109 responses. Through the dissemination of the questionnaire, the researchers were able to gather preferences and insights of the registered medical technologists regarding the difference between the electronic LIS and the paper-based methods in terms of accuracy, ease of accessioning, and ease of archiving results, which were then used as the basis for the design and programming of the proposed RbP LIS.

The phase two of the study involves the dissemination and pilot testing of the newly programmed electronic LIS. The proposed RbP LIS was tested in two (2) free-standing private laboratories in which a single request was to be accessed in both methods to establish a comparison of the effectiveness of the electronic LIS on pre-analytical and post-analytical testing. A researcher-made 5-point Likert Scale was deployed after the pilot testing to assess the electronic LIS against the traditional paper-based methods of accessioning in terms of data accuracy, ease of accessioning and ease of archiving. For the comparison of the TAT of the paper-based method and the proposed electronic LIS, the participating medical technologists were instructed to treat the specimens that will be accessioned via the Raspberry Pi LIS identical to their normal accessioning procedure using the manual paper-based method to avoid bias.

Data Analysis

For phase one, the survey was subjected to pilot testing to assess the reliability of the tool through the computation of the Cronbach's alpha. For the actual data gathering, descriptive statistics, factor analysis, and cluster analysis were done. The data was subjected to descriptive statistics to show

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the average perception of the respondents on how certain factors improve the LIS in primary and secondary laboratories. Factor analysis was used to develop a certain number of factors to be retained using the statistical tools Scree Plot and the Parallel Analysis Scree Plot. Prior to utilizing factor analysis, the data was analyzed using the Correlation Plot, Bartlett's Test of Sphericity, and Kaiser-Meyer-Olkin Test to test the relationship and factorability of the given dataset, which can help in checking the correlation and redundancy between the variables. Cluster analysis was then performed to decide the number of clusters needed and to determine which observations belong to clusters and how to divide the respondents based on their perceptions.

In analyzing the data for phase two, the Independent Sample T-test was utilized to measure the significant difference between the proposed RbP LIS and the paper-based method in terms of TAT in laboratory accessioning. Moreover, a researcher-made 5-point Likert Scale was used to gather the views of the respondents in terms of accuracy, ease of accessioning, and ease of archiving results. The mean for every statement was computed to determine which method of laboratory accessioning and archiving was more effective to use.

Ethical Considerations

The paper was reviewed and approved by the UST Faculty of Pharmacy-Ethics Review Committee on April 8, 2021. Respondents were given informed consent prior to data collection. The anonymity and confidentiality of the participants in the survey and the patients during the pilot testing were preserved during the data gathering procedure for both phases of the study as their names and identities were not revealed in the data collection, analysis, and reporting of the study. Data obtained from the surveys is protected and stored in a cloud-based shared drive where it can only be accessed by the researchers.

III. RESULTS AND DISCUSSION

Test for Reliability of Likert Scale Questionnaires

Cronbach's Alpha is possibly the most utilized instrument to measure the internal consistency and reliability quality of multiple question tests or Likert scale. Determining the internal consistency of ones' test prior to deployment is done to ensure the validity of the test/scale (Tavakol and Dennmick, 2011). The Cronbach's Alpha obtained for the likert scale questionnaire is 0.904, hence, the questionnaire is considered to have an *Excellent Reliability*. Excellent reliability is when the Cronbach's alpha of the test is $\alpha \geq 0.9$. According to Tavakol and Dennimick (2011), the value of the Cronbach's alpha is higher when the items/questions of the test are connected to each other.

Descriptive Statistics for Phase One

This provides a simple summary about the respondents' average score and ranking of the variables. The variables that were used in this statistical analysis are the core requirements of an electronic LIS obtained from the LIS-FAT questionnaire. They were treated independently and the mean for

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each variable was ranked for every factor. The ranking was done to know whether each variable is necessary for the development of the Raspberry Pi LIS and to prioritize the feature which has the highest mean score per factor.

Table 1. *Average Score of the Respondents*

Variables	Mean Score	Rank	Interpretation
Assign a unique accession number which is lab-defined to identify facility, entity and department.	4.63	6	Strongly Agree
Support alpha/numeric accession numbers	4.61	8	Strongly Agree
Allows unlimited number of patient registrations.	4.41	18	Strongly Agree
Support quick registration features.	4.66	4	Strongly Agree
Perform duplicate checks to prevent assignment of duplicate records at registration	4.70	2	Strongly Agree
Provide specimen tracking capabilities.	4.73	1	Strongly Agree
Remove unsuitable or lost specimens from the collection list and activate recollection	4.29	19	Strongly Agree
Record recollect specimen time and phlebotomist ID without losing tracking information of original collector and time.	4.42	16	Strongly Agree
Provide that uncollected specimens continue to appear on subsequent lists until cancelled or collected.	4.42	16	Strongly Agree
Create and maintain control directories and authorization tables that indicate which employees and/or terminals can enter or modify orders, enter, modify and verify results, print labels, have specimen collection responsibility and revise prep instructions.	4.62	7	Strongly Agree
View multiple special handling instructions / comments entered for test processing detail on a label. (protect from light, put on ice, spin and freeze).	4.47	13	Strongly Agree
Allow single or multiple test cancellations for each patient.	4.27	20	Strongly Agree
Print/display test requests by workstation or sub-department.	4.54	11	Strongly Agree
Test inquiry or Procedure database to only display Active and Orderable test procedures.	4.47	13	Strongly Agree
Display specimen rejection status in Order Inquiry.	4.46	15	Strongly Agree
Provide ability to generate requisitions and/or labels at order entry.	4.60	9	Strongly Agree
Place multiple tests in a single order conversation for a patient. Orders can be sent via an interface to the LIS or selected from the LIS via a test code, or by selecting from a test menu.	4.52	12	Strongly Agree

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Identify laboratory technicians who performed and reviewed tests.	4.68	3	Strongly Agree
Support printing of individual tests separately or as part of a profile.	4.65	5	Strongly Agree
Correct all parameters including verified results, retain the original value and identify the new result as CORRECTED.	4.58	10	Strongly Agree
FUNCTIONALITY	**4.54**		**Strongly Agree**
Go back to home screen after accessing data that is needed	4.40	6	Strongly Agree
Support the use of mouse and keyboard	4.82	3	Strongly Agree
Support barcode scanners	4.72	4	Strongly Agree
Branch to another computer to share important information	4.60	5	Strongly Agree
Zoom parts of the interface	4.33	7	Strongly Agree
Show notifications for extremely high values obtained from the tests	4.83	2	Strongly Agree
Save the set font sizes for each user for it to remain at that size every time the specific user logs in	4.28	8	Strongly Agree
Unique login credentials for each user	4.84	1	Strongly Agree
INTERFACE	**4.60**		**Strongly Agree**
Do multiple commands without crashing or lagging.	4.76	5	Strongly Agree
Collate data from that are coming in from a single patient across all dates and times of patient results being formulated.	4.78	2	Strongly Agree
Access patient records that are stored at any point in time with ease.	4.78	2	Strongly Agree
Store patient records in a way accessible only to personnel with access rights to these data	4.80	1	Strongly Agree
Automatically link patient information and records across sections that can share the same data.	4.63	8	Strongly Agree
Have an alternative means of accessing patient records in case of technical difficulties within the system that does correlate with the data storage.	4.74	6	Strongly Agree
Easily provide necessary patient data when needed through a single search that provides patient information.	4.78	2	Strongly Agree
Store patient data with highlighted critical values that can be recovered easily	4.70	7	Strongly Agree
PATIENT RECORD	**4.75**		**Strongly Agree**

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View unverified results online in a pending report.	4.40	7	Strongly Agree
Provide a patient testing history section for reviews such as demographics and transfusion history	4.61	3	Strongly Agree
Provide the ability for users to access general laboratory results and patient demographics and order entry screens.	4.58	5	Strongly Agree
Allow trending with the patient's previous results.	4.61	2	Strongly Agree
Correct reports-flagged to ensure the physician is aware. Accepts format sent from Reference lab interface with columns and carriage returns as needed. The display needs to be able to handle wrapping text.	4.59	4	Strongly Agree
Provide an electronic signature for signing out finalized cases.	4.28	8	Strongly Agree
Provide the ability to indicate a case has been corrected and contains an addendum after final case sign-out.	4.58	5	Strongly Agree
Specify date range, number of results, current encounter, test specific, or to display all results and tests in a patient inquiry.	4.73	1	Strongly Agree
RESULTS AND REPORTS VIEWING	**4.55**		**Strongly Agree**
Provide barcode collection and accession labels which shall contain DOB, age, and a blank line.	4.76	1	Strongly Agree
Provide barcode collection and accession labels which shall contain Patient Name, test name, collection requirements, collection container, and collection date/time.	4.75	2	Strongly Agree
Print barcode collection and accession labels on multiple industry-accepted barcode printers	4.65	6	Strongly Agree
Support delta checking	4.67	5	Strongly Agree
Provides automatic warnings if lab-defined result thresholds are exceeded when resulting	4.72	3	Strongly Agree
Update inventory when blood orders or other expendable items are ordered.	4.63	7	Strongly Agree
Provide a method such as a backup feature for the packing list (which generates the interface message to the reference lab) allowing it to be recalled if an error is encountered.	4.71	4	Strongly Agree
ADDITIONAL FEATURES	**4.70**		**Strongly Agree**

Note. Verbal Interpretation of the Weighted Mean Legend

1.00 to 1.80	Strongly Disagree
1.81 to 2.61	Disagree
2.62 to 3.42	Neutral

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3.43 to 4.23	Agree
4.24 to 5.00	Strongly Agree

Table 1 shows the average preference of the respondents on how the following factors improve the Laboratory Information System (LIS) in Primary and Secondary Laboratories.
In terms of Functionality, the respondents Strongly Agree that Functionality improves the Laboratory Information System (LIS) in Primary and Secondary Laboratories with an average of 4.54. The respondents strongly agree that the LIS providing specimen tracking capabilities help most on their needs with the highest score of 4.73. According to Kammergruber and Durner (2018), specimen tracking or check-in and checkout are the most important information when it comes to LIS. Laboratories opted to carry out a tracking system due to increasing volume of specimens, complexity of some procedures and the desire to lessen the turnaround time and the operating cost (Hanna and Pantanowitz, 2016). Meanwhile respondents strongly agree the least that the LIS which allows single or multiple test cancellations for each patient helps their needs with the lowest mean score of 4.27. Cancelled tests in laboratories are considered as waste in resources and can affect patient care (Canales and Fang, 2016).

In terms of Interface, the respondents Strongly Agree that Interface improves the Laboratory Information System (LIS) in Primary and Secondary Laboratories with an average of 4.60. The respondents strongly agree that the LIS having a Unique login credentials for each user helps most on their needs with the highest score of 4.84. Security from unauthorized internal and external access is a key requirement for an ideal laboratory information system. This feature will help in protecting the confidentiality of the data. For a more secure interface, advanced login capabilities are ideal (Sepulveda & Young, 2013). Meanwhile respondents strongly agree the least that the LIS which allow to save the set font sizes for each user for it to remain at that size every time the specific user logs in helps their needs with the lowest score of 4.28.

In terms of Patient Record, the respondents Strongly Agree that Patient Recording improves the Laboratory Information System (LIS) in Primary and Secondary Laboratories with an average of 4.75. According to Henricks (2011), patient recording electronically can influence the laboratory information management with regards to the patient care, specifically in reporting results. The respondents strongly agree that the LIS having a Store patient records in a way accessible only to personnel with access rights to these data help most on their needs with the highest score of 4.80. According to Sepulveda & Young (2013), patient records must be protected from uncredited people and access must be limited to laboratory personnel. Meanwhile respondents strongly agree the least is that the LIS which allows to Automatically link patient information and records across sections that can share the same data help their needs with the lowest score of 4.63.

In terms of Results and Reports Viewing, the respondents Strongly Agree that Results and Reports Viewing improves the Laboratory Information System (LIS) in Primary and Secondary Laboratories with an average of 4.55. The respondents strongly agree that the LIS having a Specify date range, number of results, current encounter, test specific, or to display all results and tests in a patient inquiry help most on their needs with the highest score of 4.73. The LIS should allow electronic signatures for a more reliable data authentication (Sepulveda & Young, 2013). However, in this factor, the respondents strongly agree the least that the LIS which allows the provision of

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an electronic signature for signing out finalized can help their needs. It yielded the lowest score of 4.28 which makes it the least priority in this section.

In terms of Additional Features, the respondents Strongly Agree that the Additional Features improves the Laboratory Information System (LIS) in Primary and Secondary Laboratories with an average of 4.70. The respondents strongly agree that the LIS that provides barcode collection and accession labels which shall contain DOB, age, and a blank line help most on their needs with the highest score of 4.76. According to Lukić (2017), barcoded specimens prevent errors in identifying the samples. Furthermore, this type of feature in specimen accessioning and processing is fundamental for an ideal LIS since a barcode can readily contain larger amounts of information regarding the patient and the specimen itself (Sepulveda & Young, 2013). Meanwhile, respondents strongly agree the least that the LIS which allows to Update inventory when blood orders or other expendable items are ordered help their needs with the lowest score of 4.63.

Factor Analysis

In this section, we utilize the variables in the series of questions pertaining to the respondents' perceived factors that will help in knowing and designing an ideal Alternative Laboratory Information System (LIS) in Primary and Secondary Laboratories.

Test for adequacy of data

Before performing factor analysis, it is necessary to test the adequacy of the data. Correlation Plot was utilized to check whether the variables have an inverse or direct relationship. Subsequently, the researchers used the Bartlett's Test of Sphericity and the Kaiser-Meyer-Olkin Test. The aforementioned tests are used to test the factorability of the given dataset which can help in checking the correlation and redundancy between the variables. Bartlett's Test of Sphericity examines the entire correlation matrix. This would determine whether the variables are correlated to each other which will then be the basis whether it will be suitable for dimension reduction. A value of less than 0.05 is considered to be significant. Kaiser-Meyer-Olkin Test is a statistical test that assesses the appropriateness of using factor analysis on the given dataset. High values generally indicate that a factor analysis is applicable. The index varies from 0 to 1, with 1 indicating that each variable is correctly predicted by the other variables without deviation. The following parameters can be used to interpret the measure: A result of .80 or higher is considered commendable; a result of .70 or higher is considered moderate; a score of .60 or higher is considered mediocre; a score of .50 or higher is considered terrible; and a score of .50 or lower is considered unsuitable. The researcher should always have an overall Measure of Sampling Adequacy (MSA) value of above .50 before proceeding with the factor analysis (Hair et al., 2019).

Figure 1. *Correlation Plot*

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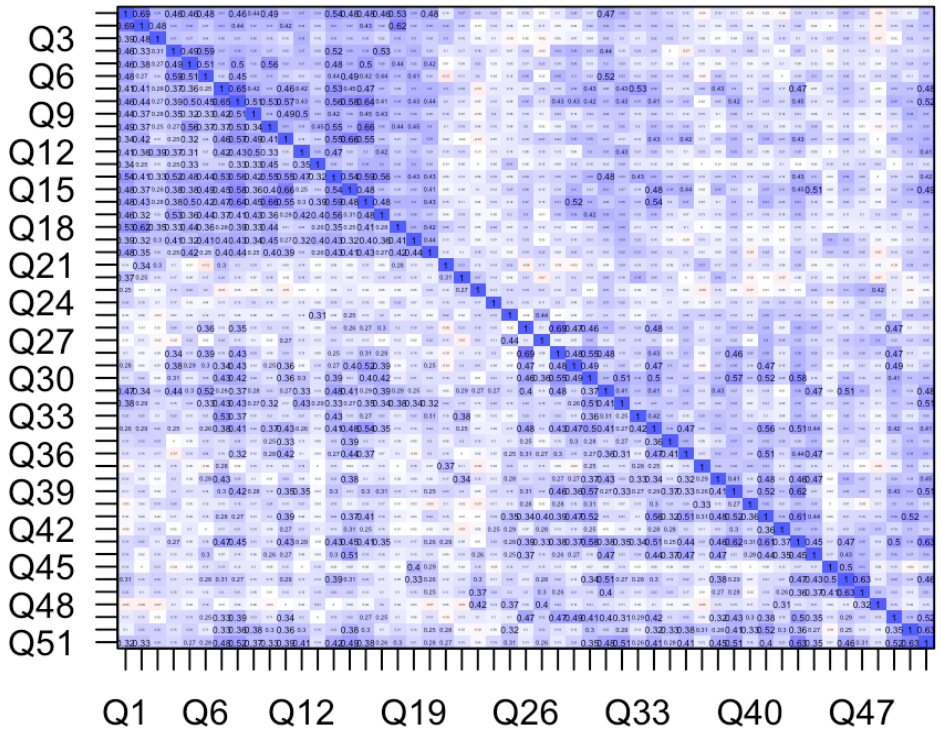

Figure 1 provides a visual representation on the strength of correlation between the variables. Direct relationships are represented by the color blue, while the color red shows an inverse relationship. It can be shown that most of the variables have a direct relationship.

Table 2. *Bartlett's Test of Sphericity*

Test Statistic	DF	P - Value
3770.967	1275	<0.001

Table 2 shows the questions' Bartlett's Test of Sphericity. At 0.05 level of significance, the null hypothesis that the correlation matrix is an identity matrix is rejected ($p<0.001$). This indicates that the variables are related to each other, hence, the suitability for factor analysis.

Table 3. *Kaiser-Meyer-Olkin Factor Adequacy*

Overall MSA: 0.72			
Q1	0.79	Q27	0.67
Q2	0.73	Q28	0.75
Q3	0.72	Q29	0.65
Q4	0.70	Q30	0.75

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Q5	0.84	Q31	0.83
Q6	0.70	Q32	0.77
Q7	0.74	Q33	0.52
Q8	0.91	Q34	0.76
Q9	0.76	Q35	0.71
Q10	0.73	Q36	0.75
Q11	0.79	Q37	0.58
Q12	0.62	Q38	0.66
Q13	0.60	Q39	0.73
Q14	0.84	Q40	0.79
Q15	0.80	Q41	0.71
Q16	0.86	Q42	0.64
Q17	0.74	Q43	0.81
Q18	0.74	Q44	0.63
Q19	0.80	Q45	0.38
Q20	0.73	Q46	0.73
Q21	0.56	Q47	0.75
Q22	0.56	Q48	0.49
Q23	0.45	Q49	0.74
Q24	0.44	Q50	0.64
Q25	0.68	Q51	0.79
Q26	0.75		

Table 3 shows the Kaiser-Meyer-Olkin Test for the overall measure of sampling adequacy. With an overall MSA of 0.72, which is greater than the standard 0.60, the researchers can perform factor analysis. Because of this, even variables with individual MSA less than 0.50 will not be omitted. Omission of variables will only be necessary if overall MSA did not reach 0.60.

Determining the number of factors

To determine the number of factors, the researchers used the elbow method scree plots and parallel analysis scree plots. Figures 2 and 3 below show the Scree Plot and the Parallel Analysis Scree Plot, respectively.

Figure 2. *Scree Plot*

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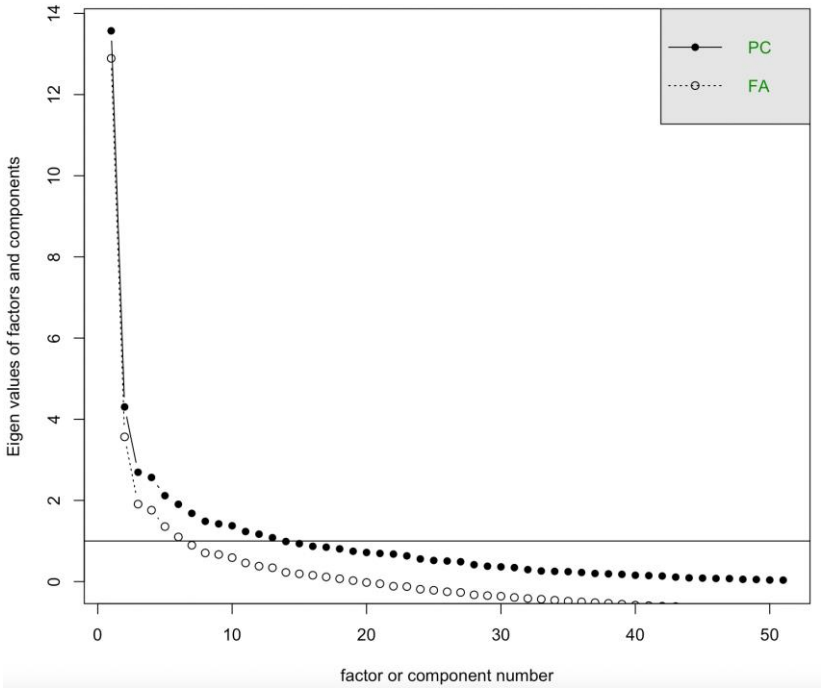

Scree plot is a statistical tool commonly used by plotting the eigenvalues of factors against the number of factors determining the "elbow" of the curve. This "elbow" is the point where the slope of the curve first begins to flatten and approximately form a horizontal line (Hair et al., 2019). The points above the "elbow" are considered to be the ideal number of factors to be retained (Osborne, 2014), although some researchers suggest that the inflection point or the elbow should be included (Hair et al., 2019). By inspecting the figure above, the scree plot elbow method suggests that thirteen factors should be retained by counting the principal components (PC) above the regression line with an eigenvalue of greater than 1. According to Velicer et al. (2000), scree plot is recommended to be used supplemented by other procedures, but not as an independent procedure. Moreover, some of the graphs may show several or no obvious points. Interpretation of scree plot can be highly subjective (Woods & Edwards, 2011), thus, further analysis with another procedure is needed to make a more accurate interpretation.

Figure 3. *Parallel Analysis Scree Plot*

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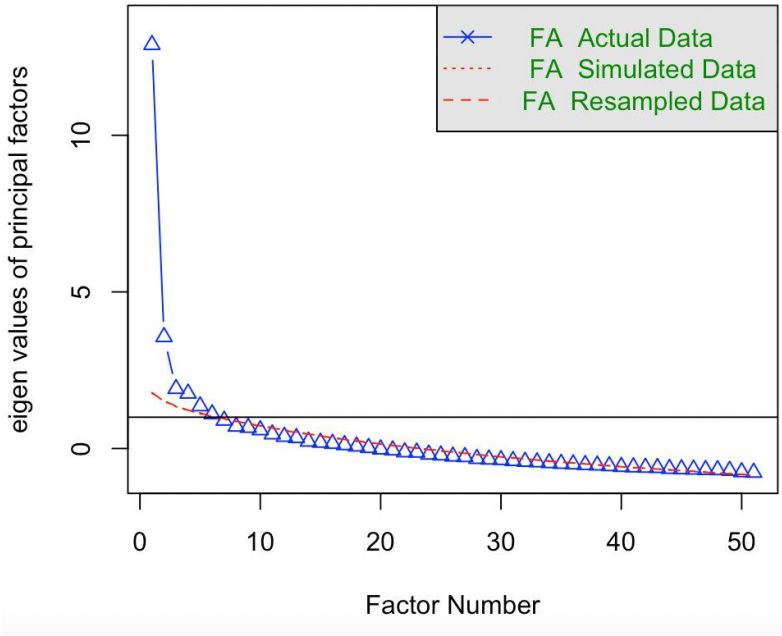

The researchers utilized parallel analysis which generates random uncorrelated data (Osborne, 2014). The eigenvalue from the original data is compared from those generated average eigenvalues of each factor in the simulated data set. This test suggests that the upper limit, 95th percentile, of the simulated eigenvalues will be used as a threshold and that all factors whose eigenvalues are higher than the simulated data set will be retained (Hair et al., 2019). After executing the Parallel Analysis Scree Plot, it suggests that only five factors should be retained by counting the FA actual data above the regression line. Thus, we only retain five factors from the initial fifty-one variables.

The researchers rotated their data matrix using VARIMAX rotation to appropriately analyze the data. This yielded the following table of factor loadings of every variable for each five factors.

Table 4. *Factor Loadings of the Variable*

Variables	1	2	3	4	5
Assign a unique accession number which is lab-defined to identify facility, entity and department.	0.77	-0.14	0.1	0.21	0.16
Support alpha/numeric accession numbers	0.66	0.08	-0.09	-0.02	0.34
Allows unlimited number of patient registrations.	0.49	0.04	-0.11	0.09	0.24
Support quick registration features.	0.55	-0.16	0.4	0.06	0.14
Perform duplicate checks to prevent assignment of duplicate records at registration	0.69	0.06	0.13	0.09	-0.12
Provide specimen tracking capabilities.	0.55	-0.07	0.44	0.25	-0.11

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Remove unsuitable or lost specimens from the collection list and activate recollection	0.52	0.23	0.17	-0.02	0.47
Record recollect specimen time and phlebotomist ID without losing tracking information of original collector and time.	0.66	0.28	0.35	-0.01	0.14
Provide that uncollected specimens continue to appear on subsequent lists until cancelled or collected.	0.58	0.19	0.09	-0.09	0.17
Create and maintain control directories and authorization tables that indicate which employees and/or terminals can enter or modify orders, enter, modify and verify results, print labels, have specimen collection responsibility and revise prep instructions.	0.71	0.21	0.11	-0.08	-0.04
View multiple special handling instructions / comments entered for test processing detail on a label. (protect from light, put on ice, spin and freeze).	0.50	0.55	0.19	-0.05	-0.05
Allow single or multiple test cancellations for each patient.	0.50	0.11	0.05	-0.05	0.39
Print/display test requests by workstation or sub-department.	0.55	0.10	-0.06	0.14	-0.11
Test inquiry or Procedure database to only display Active and Orderable test procedures.	0.68	0.19	0.27	0.06	0.15
Display specimen rejection status in Order Inquiry.	0.55	0.45	0.23	0.17	-0.09
Provide ability to generate requisitions and/or labels at order entry.	0.68	0.33	0.31	-0.07	-0.03
Place multiple tests in a single order conversation for a patient. Orders can be sent via an interface to the LIS or selected from the LIS via a test code, or by selecting from a test menu.	0.54	0.01	0.4	0.01	0.11
Identify laboratory technicians who performed and reviewed tests.	0.64	-0.02	-0.02	0.06	0.17
Support printing of individual tests separately or as part of a profile.	0.62	-0.06	0.04	0.19	0.13
Correct all parameters including verified results, retain the original value and identify the new result as CORRECTED.	0.58	0.15	0.03	0.18	0.06
Go back to home screen after accessing data that is needed	0.12	0.18	-0.22	0.04	0.64
Support the use of mouse and keyboard	0.16	-0.28	0.21	0.21	0.52
Support barcode scanners	0.05	-0.12	0.12	0.69	-0.04
Branch to another computer to share important information	0.12	0.07	0.11	0.20	0.23
Zoom parts of the interface	0.04	0.47	-0.12	0.39	0.12
Show notifications for extremely high values obtained from the tests	0.1	0.06	0.77	0.14	-0.01
Save the set font sizes for each user for it to remain at that size every time the specific user logs in	0.02	0.49	-0.06	0.37	0.12
Unique login credentials for each user	0.08	0.09	0.79	0.12	0.03
Do multiple commands without crashing or lagging.	0.23	0.19	0.68	0.06	-0.1
Collate data from that are coming in from a single patient across all dates and times of patient results being formulated.	0.14	0.32	0.57	0.02	0.37
Access patient records that are stored at any point in time with ease.	0.35	0.01	0.45	0.42	0.28

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Store patient records in a way accessible only to personnel with access rights to these data	0.39	0.15	0.19	0.17	0.37
Automatically link patient information and records across sections that can share the same data.	0.20	0.01	0.32	0.06	0.51
Have an alternative means of accessing patient records in case of technical difficulties within the system that does correlate with the data storage.	0.25	0.41	0.51	0.05	0.21
Easily provide necessary patient data when needed through a single search that provides patient information.	0.15	0.39	0.23	0.10	0.08
Store patient data with highlighted critical values that can be recovered easily	0.13	0.62	0.24	0.1	0.02
View unverified results online in a pending report.	-0.01	0.26	0.03	-0.12	0.55
Provide a patient testing history section for reviews such as demographics and transfusion history	-0.03	0.29	0.36	0.30	0.42
Provide the ability for users to access general laboratory results and patient demographics and order entry screens.	0.10	0.42	0.41	0.03	0.41
Allow trending with the patient's previous results.	0.01	0.33	0.35	-0.21	0.18
Correct reports-flagged to ensure the physician is aware. Accepts format sent from Reference lab interface with columns and carriage returns as needed. The display needs to be able to handle wrapping text.	0	0.72	0.40	0.04	0.12
Provide an electronic signature for signing out finalized cases.	0.04	0.59	0.03	0.18	0.01
Provide the ability to indicate a case has been corrected and contains an addendum after final case sign-out.	0.13	0.55	0.42	0.17	0.38
Specify date range, number of results, current encounter, test specific, or to display all results and tests in a patient inquiry.	0.07	0.41	0.34	0.45	0.02
Provide barcode collection and accession labels which shall contain DOB, age, and a blank line.	0.13	0.06	-0.04	0.51	-0.01
Provide barcode collection and accession labels which shall contain Patient Name, test name, collection requirements, collection container, and collection date/time.	0.2	0.23	0.11	0.64	0.26
Print barcode collection and accession labels on multiple industry-accepted barcode printers	0.1	0.15	0.12	0.74	0.14
Support delta checking	-0.07	0.22	0.15	0.50	-0.11
Provides automatic warnings if lab-defined result thresholds are exceeded when resulting	0.06	0.29	0.58	0.13	0.18
Update inventory when blood orders or other expendable items are ordered.	0.23	0.65	0.02	-0.05	0.27
Provide a method such as a backup feature for the packing list (which generates the interface message to the reference lab) allowing it to be recalled if an error is encountered.	0.35	0.51	0.14	0.19	0.39

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Table 5. *Factor Classification*

Proposed Factor Clarification	Variables
General Features	Assign a unique accession number which is lab-defined to identify facility, entity and department.
	Support alpha/numeric accession numbers
	Allows unlimited number of patient registrations.
	Support quick registration features.
	Perform duplicate checks to prevent assignment of duplicate records at registration
	Provide specimen tracking capabilities.
	Remove unsuitable or lost specimens from the collection list and activate recollection
	Record recollect specimen time and phlebotomist ID without losing tracking information of original collector and time.
	Provide that uncollected specimens continue to appear on subsequent lists until cancelled or collected.
	Create and maintain control directories and authorization tables that indicate which employees and/or terminals can enter or modify orders, enter, modify and verify results, print labels, have specimen collection responsibility and revise prep instructions.
	View multiple special handling instructions / comments entered for test processing detail on a label. (protect from light, put on ice, spin and freeze).
	Allow single or multiple test cancellations for each patient.
	Print/display test requests by workstation or sub-department.
	Test inquiry or Procedure database to only display Active and Orderable test procedures.
	Display specimen rejection status in Order Inquiry.
	Provide ability to generate requisitions and/or labels at order entry.
	Place multiple tests in a single order conversation for a patient. Orders can be sent via an interface to the LIS or selected from the LIS via a test code, or by selecting from a test menu.
	Identify laboratory technicians who performed and reviewed tests.
	Support printing of individual tests separately or as part of a profile.

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	Correct all parameters including verified results, retain the original value and identify the new result as CORRECTED.
	Store patient records in a way accessible only to personnel with access rights to these data
Results and Report Viewing	View multiple special handling instructions / comments entered for test processing detail on a label. (protect from light, put on ice, spin and freeze).
	Save the set font sizes for each user for it to remain at that size every time the specific user logs in
	Easily provide necessary patient data when needed through a single search that provides patient information.
	Store patient data with highlighted critical values that can be recovered easily
	View unverified results online in a pending report.
	Provide a patient testing history section for reviews such as demographics and transfusion history
	Provide the ability for users to access general laboratory results and patient demographics and order entry screens.
	Allow trending with the patient's previous results.
	Correct reports-flagged to ensure the physician is aware. Accepts format sent from Reference lab interface with columns and carriage returns as needed. The display needs to be able to handle wrapping text.
	Provide an electronic signature for signing out finalized cases.
	Provide the ability to indicate a case has been corrected and contains an addendum after final case sign-out.
	Update inventory when blood orders or other expendable items are ordered.
	Provide a method such as a backup feature for the packing list (which generates the interface message to the reference lab) allowing it to be recalled if an error is encountered.
Archiving Features	Show notifications for extremely high values obtained from the tests
	Do multiple commands without crashing or lagging.
	Collate data from that are coming in from a single patient across all dates and times of patient results being formulated.
	Access patient records that are stored at any point in time with ease.
	Have an alternative means of accessing patient records in case of technical difficulties within the system that does correlate with the data storage.
	Allow trending with the patient's previous results.
	Provides automatic warnings if lab-defined result thresholds are exceeded when resulting
Additional Features	Support barcode scanners
	Zoom parts of the interface
	Specify date range, number of results, current encounter, test specific, or to display all results and tests in a patient inquiry.

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	Provide barcode collection and accession labels which shall contain DOB, age, and a blank line.
	Provide barcode collection and accession labels which shall contain Patient Name, test name, collection requirements, collection container, and collection date/time.
	Print barcode collection and accession labels on multiple industry-accepted barcode printers
	Support delta checking
Accessioning Feature	Go back to home screen after accessing data that is needed
	Support the use of mouse and keyboard
	Branch to another computer to share important information
	Automatically link patient information and records across sections that can share the same data.
	View unverified results online in a pending report.
	Provide a patient testing history section for reviews such as demographics and transfusion history

With the results above, the researchers came up with the following factor classifications below. Table 5 shows the factor classification of the factor loadings yielded in Table 4. The variables on factor 1 focuses on the General Features the LIS must have. The next is that LIS must also contain User-Interface Features. The respondents also agreed that additional factors are supplementary for an LIS. The variables on factor 4 focuses on Accessioning Features. Lastly, LIS must contain Results and Report Viewing Features.

Table 6. *Summary of Variance Explained by the Factors*

Factor	Eigenvalue	% Variance Explained	% Cumulative Variance Explained
General Features	8.25	16%	16%
Results and Report Viewing	5.15	10%	26%
Archiving Features	5.11	10%	36%
Additional Features	3.41	7%	43%
Accessioning Feature	3.33	7%	50%

Table 6 shows the corresponding eigenvalues of the factors along with how much of the variability each factor explains and its contribution to the variability explained by all five factors. All the five factors explain a total of 50% variability in the responses of the respondents.

Cluster Analysis

After the analysis of the factors, the respondents are then segmented based on which characteristics best describe each factor. The matrix of factors obtained earlier are used to cluster the respondents.

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Agglomerative Clustering with Ward's method was employed to determine the observations that belong to which clusters. According to Abdullah, Rostamzadeh, Sedig, Garg and McArthur (2020), Cluster analysis can be used to uncover different patterns in laboratory records/hospital records by different varieties of grouping entities such as medications and patients that have similar characteristics into homogeneous groups and it has great capability to characterize records into meaningful clusters. Meanwhile, to decide the number of clusters to be formed, Silhouette Statistics methods were consulted.

Figure 4. *Silhouette Statistics Per Cluster*

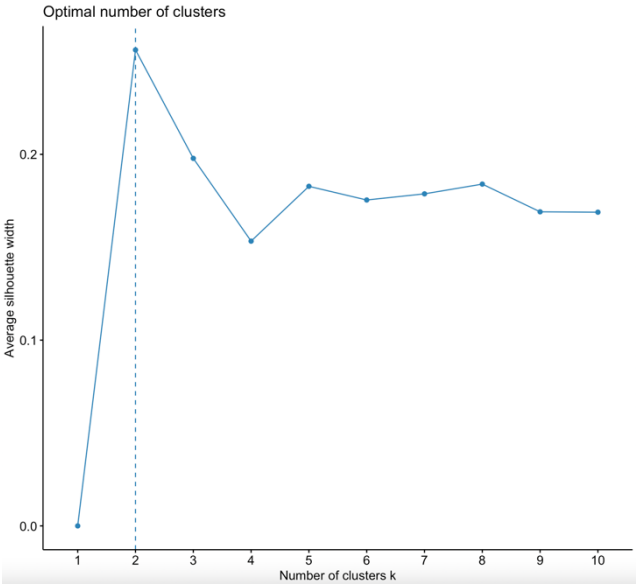

Figure 4 shows the graph on the Silhouette Statistics per cluster. Based on the graph, the ideal number of clusters are 2 groups of clustering.

Table 7. *Cluster Means per Factor*

Factors	Cluster 1 (n=49)	Cluster 2 (n=60)
General Features	-0.09	0.07
Results and Report Viewing	-0.36	0.29
Archiving Features	-0.18	0.15
Additional Features	-0.09	0.08
Accessioning Feature	-0.54	0.44

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Table 7 represents the respondent's cluster means per factor. It is shown that cluster 1 are those respondents who relatively agree the least on having the features mentioned to help improve the LIS in Primary and Secondary Laboratories with a negative score for each factor shown. Overall, this cluster are the respondents that have a negative approach toward the LIS and its factors. According to Aldosari, Gadi, Alanazi and Househ (2017), introduction of new and modern technology to the users can greatly affect the user's performance due to not considering their account regarding the system during the implementation. Usability issues like insufficient users' involvement and training in adaptation of the new system can add to the disappointment and negative outlook of the users on the system (Peute and Jaspers, 2007). According to Vogelsmeier, Halbesleben And Scott-Cawiezell (2008), if the users find the Programme difficult to understand and complicated for them, they tend to think of alternative ways to do the task than to struggle with the system and make the job more slow than usual. Meanwhile, those respondents in cluster 2 are those who greatly agree that the mentioned factors are helpful to improve the LIS in Primary and Secondary Laboratories with a positive score for each factor shown. While cluster 2 shows that there is indeed a belief from respondents that the factors mentioned above provide help in improving the LIS, many individuals may perceive the LIS as simply a "black-box" into which orders are sent and from which results emerge (Sinard et al., 2015). This may explain why respondents whose data fall into cluster 1 believe least on features that may help improve their experience with the LIS. Nevertheless, a department-specific approach to information system deployment and management within a health care system creates a need to develop and support systems integration via multiple interfaces (Sinard et al., 2015).

Comparison of the RbP LIS and paper-based method in terms of turnaround time

In both pre-analytical and post-analytical stages, the researchers utilized test statistics to compare the turnaround time when using the RbP LIS and the paper-based approach. The mean TAT obtained for both processes is shown in the tables below.

Table 8. *Difference of the RbP LIS and paper-based method in terms of turnaround time on the pre-analytical process*

Variables		Mean TAT (mins)	Computed Test Statistic	P-value	Interpretation
Pre-Analytical	LIS turnaround time	13.85	-14.25	<0.001	There is a significant difference in the scores of the two groups.
	Paper-Based turnaround time	29.20			

$\alpha = 0.05$

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Table 8 shows whether there is a significant difference between the RbP LIS procedure turnaround time compared to the traditional paper-based methods procedure turnaround time before testing (pre-analytical). With a Test Statistic of t = -14.25 and a p-value of <0.001, which is less than 0.05, there is a significant difference in the RbP LIS procedure turnaround time compared to the traditional paper-based methods procedure turnaround time before testing (pre-analytical). It can be shown that the procedure turnaround time was faster with the RbP LIS program with an average of 13.85 minutes, while the paper-based methods have an average of 29.20 minutes. From the results, it can be seen that the use of RbP LIS in laboratory accessioning reduces the turnaround time by as much as half compared to the manual paper-based method. The manual hand writing of all patient data as well as ordering of tests is time consuming, unlike the electronic test request which accelerates admission desk procedures (Lukić, 2017).

Table 9. *Difference of the LIS Independent Sample T-Test of procedure turnaround time after testing (post-analytical)*

Variables		Mean TAT (mins)	Computed Test Statistic	P-value	Interpretation
Post-Analytical	LIS turnaround time	21.29	-13.29	<0.001	There is a significant difference in the scores of the two groups.
	Paper-Based turnaround time	39.36			

$\alpha = 0.05$

Table 9 shows whether there is a significant difference between the RbP LIS procedure turnaround time compared to the traditional paper-based methods procedure turnaround time after testing (post-analytical). With a Test Statistic of t = -13.29 and a p-value of <0.001, which is less than 0.05, there is a significant difference in the RbP LIS procedure turnaround time compared to the traditional paper-based methods procedure turnaround time after testing (post-analytical). It can be shown that the procedure turnaround time was faster with the RbP LIS program with an average of 21.29, while the paper-based methods have an average of 39.36 minutes. This acknowledges the need of incorporating a laboratory information system into the actual clinical setting. Manually generating written reports can be time consuming and difficult to understand, increasing the chance

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of identification errors owing to variations in handwriting. Clinicians may have difficulty archiving data with this system, as results may not be readily available and accessible (Lukić, 2017).

Overall, reduced turnaround time remains to be desirable for a laboratory to improve the quality of healthcare they provide. The constant monitoring of the turnaround time is one way to prove a laboratory's commitment in providing greater performance and user satisfaction (Hawkins, 2007).

Assessment of Accuracy, Ease of Accessioning, and Ease of Archiving using the RbP LIS

After the pilot testing of the RbP LIS, data from the factors stated regarding the LIS were assessed and compared to the traditional paper-based method of accessioning to establish significant differences between them. Variables are also ranked based on the respondents' data.

Table 10. *Mean Score of the Respondents on the Assessment of Accuracy, Ease of Accessioning, and Ease of Archiving using the RbP LIS*

Variables	Mean Score	Rank	Interpretation
1. Using the LIS allows to obtain more accurate patient information compared to the traditional paper-based method.	**4.44**	5	Strongly Agree
2. Using the LIS allows to change mistakenly entered patient information faster than traditional paper- based methods.	**4.67**	1	Strongly Agree
3. Using the LIS limits accessioning errors compared to traditional paper-based methods.	**4.67**	1	Strongly Agree
4. Validation of test results is much easier when using LIS compared to paper-based methods.	**4.67**	1	Strongly Agree
5. Entry and validation of results are much faster when using LIS compared to traditional paper-based methods.	**4.67**	1	Strongly Agree
ACCURACY	**4.62**		**Strongly Agree**
6. Results can be accessed with ease when using LIS compared to traditional paper-based methods.	**4.78**	1	Strongly Agree

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7. Patient details can be located faster when using LIS compared to traditional paper-based methods.	**4.67**	2	Strongly Agree
EASE OF ACCESSIONING	**4.72**		**Strongly Agree**
8. Audit trails are easily seen by the administrators when using LIS compared to paper-based methods.	**4.33**	8	Strongly Agree
9. Documentation and management records are more precise when using LIS compared to traditional paper-based methods.	**4.67**	1	Strongly Agree
10. Previous records of patients are easily linked and merged with their new results when using LIS compared to traditional paper-based methods.	**4.67**	1	Strongly Agree
11. Delta checking is much faster when using LIS compared to paper-based methods.	**4.56**	6	Strongly Agree
12. Viewing previous and current patient results are much faster when using LIS compared to paper-based methods.	**4.67**	1	Strongly Agree
13. Patient history results can be easily stored when using LIS compared to paper-based methods.	**4.67**	1	Strongly Agree
14. Patient documents are more organized when using LIS compared to paper-based methods.	**4.67**	1	Strongly Agree
15. Amendment of test results are much more organized when using LIS compared to paper-based methods.	**4.56**	6	Strongly Agree
EASE OF ARCHIVING	**4.60**		**Strongly Agree**

Note. Verbal Interpretation of the Weighted Mean Legen

1.00 to 1.80 Strongly Disagree
1.81 to 2.61 Disagree
2.62 to 3.42 Neutral
3.43 to 4.23 Agree

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4.24 to 5.00 Strongly Agree

Table 10 shows the effectiveness of the RbP LIS compared to the traditional paper-based methods in terms of Accuracy, Ease of Accessioning and Ease of Archiving.

In terms of Accuracy, the respondents strongly agree that the RbP LIS is effective compared to the traditional paper-based methods with an average score of 4.62. The respondents equally strongly agree the most that using the RbP LIS allows to change mistakenly entered patient information faster than traditional paper based method, that using the RbP LIS limits accessioning errors compared to traditional paper based method, that validation of test results are much easier when using RbP LIS compared to paper based method and that entry and validation of results are much faster when using RbP LIS compared to traditional paper based method with the highest mean score of 4.67. Meanwhile, the respondents strongly agree the least that using the RbP LIS allows to obtain more accurate patient information compared to the traditional paper based method with the lowest mean score of 4.44. The following responses support the claim of the RbP LIS with regards to accuracy because according to Paszko & Pugsley (2000), an LIS can significantly enhance data quality by verifying data format, reducing data entry errors, and limiting users to selecting a test or method from a pull-down list.

In terms of Ease of Accessioning, the respondents strongly agree that the RbP LIS is effective compared to the traditional paper-based methods in terms of Ease of Accessioning with an average score of 4.72. The respondents strongly agree the most that results can be accessed with ease when using the RbP LIS compared to traditional paper-based methods with the highest mean score of 4.78. Meanwhile, the respondents strongly agree the least that patient details can be located faster when using RbP LIS compared to traditional paper-based methods with the lowest mean score of 4.67. It is important to note the value of accessioning as Henricks (2015) states that correct patient-specimen identification is of paramount importance when accessioning, because this process reduces the risk of patient misidentification or selection of the incorrect patient.

In terms of Ease of Archiving, the respondents strongly agree that the RbP LIS is effective compared to the traditional paper-based methods in terms of Ease of Accessioning with an average score of 4.60. The respondents strongly agree the most that the documentation and management records are more precise when using RbP LIS compared to traditional paper based method, that the previous records of patients are easily linked and merged with their new results when using RbP LIS compared to traditional paper based method, that the viewing previous and current patient results are much faster when using RbP LIS compared to paper based method, that the patient history results can be easily stored when using RbP LIS compared to paper based method, and that the patient documents are more organized when using RbP LIS compared to paper based method with the highest mean score of 4.67. Meanwhile, the respondents strongly agree the least that the audit trails are easily seen by the administrators when using LIS compared to paper-based methods with the lowest mean score of 4.33. The value of historical data assets can be maintained by ensuring continued accessibility of this data in a single application (Prasad & Bodhe, 2012). An

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LIS can significantly enhance data quality by providing an audit trail, and decreasing data search time (Paszko & Pugsley, 2000).

IV. CONCLUSIONS AND RECOMMENDATIONS

This study was created to establish the significant differences between the use of the RbP LIS and the paper-based method of accessioning in an actual laboratory setting. In order to achieve this, the researchers created a survey based on LIS-FAT to establish what the respondents deem as the most important features that are to be implemented on the RbP LIS. Different parameters were measured in order to differentiate the performance of the two aforementioned methods of accessioning and the researchers were able to derive the following conclusions from the study:

As for the preferences of the respondents that are derived from the initial survey, the respondents were able to provide various features that are deemed to be most important based on the following factors: the functionality, the interface, the patient record feature, the results and reports viewing, and the additional features of the electronic LIS. This information was used to implement features in the RbP LIS that caters to the respondents' needs. Various features that were deemed to be the most important are: the LIS's specimen tracking capabilities, a unique login credential, the ability to display results and tests in a patient inquiry, and the ability to provide barcode collections and accession labels which contains DOB, age, and a blank line.

The results from the Independent Sample T-test which are a test statistic of $t = -13.29$ and a p-value of <0.001, (less than 0.05) signifies that there is indeed a significant difference between the proposed RbP LIS procedure turnaround time compared to the traditional paper-based methods procedure turnaround time before testing (pre-analytical).

Moreover, the effectiveness of the RbP LIS when being compared to traditional paper-based method of accessioning were also measured on the following parameters: accuracy, ease of accessioning, and ease of archiving. It is concluded based on the three aforementioned parameters that the RbP LIS far outweighs the paper-based method of accessioning. The RbP LIS allows for a change in mistakenly entered patient information and this limit accessioning errors. Results can also be accessed more easily with the RbP LIS, and the documentation and management records are more precise and previous records of patients are easily linked and merged with their new results which allows for viewing of these results to be faster.

The ongoing pandemic at the time of the experiment limits the scope of this study. Due to time constraints, researchers were only able to conduct limited tests, and the length of survey data collection was shortened. In future studies, the survey regarding electronic LIS features should be conducted more thoroughly and with a larger number of respondents to attain greater variability in responses. For more accurate findings and comparison, it is advised that the RbP LIS software be tested for a longer period of time in actual laboratory settings. Moreover, it is recommended to expand the study area because there are laboratories in other provinces that still use the manual or traditional paper-based method in their workflow.

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Future researchers should explore additional variables on RbP LIS functionality to broaden the scope of the study and test the RbP LIS storage capacity to provide more efficiency in the utilization of RbP LIS. Upgrading the RbP LIS program to showcase more features, is recommended to accommodate tertiary-level laboratories.

A simultaneous test run would be advantageous for a more accurate comparison of RbP LIS and the paper-based approach. It is suggested that laboratory administrators provide their healthcare personnel with the essential skills in order to bridge the gap between the use of a manual logbook approach and RbP LIS. The development of platforms aimed at transitioning from traditional paper-based techniques to the use of an electronic LIS would be extremely beneficial and useful to laboratories considering these changes.

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