RESEARCH PAPER

From Descriptive Workflow To Quantitative Performance: A Time-Motion Study of Laboratory Turnaround Time Using Lundberg'S Model

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ABSTRACT

Turnaround Time (TAT) is a key performance indicator in clinical laboratory services, as it directly affects diagnostic accuracy, clinical service efficiency, and patient satisfaction. This study aimed to analyze the service time performance of a clinical chemistry laboratory and to identify factors influencing TAT achievement across each phase of the laboratory testing process using a time-and-motion study approach and a laboratory workflow model. This observational study employed a cross-sectional design and was conducted at the laboratory of Hospital X in Surabaya during April–May 2025. The study sample consisted of 948 clinical chemistry blood specimens collected over eight randomly selected observation days during the morning shift. Data were obtained through direct, non-interventional observation and analyzed descriptively, with Chi-square tests used to examine the association between service time variations at each service station and TAT achievement. The results showed that the average total laboratory service time reached 186 minutes, exceeding the established TAT standard (<140 minutes). A total of 56.3% of examinations failed to meet the standard TAT, with the most substantial delays occurring in the pre-analytical phase, particularly during patient registration and sample collection queueing. Chi-square analysis demonstrated a statistically significant association between service time variations across all service stations (registration, phlebotomy, analytical, and post-analytical phases) and TAT achievement ($p < 0.05$). Despite these delays, patient satisfaction regarding service quality and laboratory accessibility remained very high, while the provision of information was identified as an aspect requiring improvement. This study emphasizes that optimizing service management workflows and strategically allocating resources during peak hours are critical strategies for improving turnaround time performance in clinical laboratories.

Keywords: Turnaround Time; Clinical Laboratory; Time and Motion Study; Pre-Analytical Phase; Laboratory Service Quality.

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INTRODUCTION

A clinical laboratory is a healthcare facility that provides diagnostic testing of clinical specimens to obtain information on individual health status, primarily to support disease diagnosis, treatment, and recovery (Ministry of Health Regulation No. 43/2013). Clinical laboratories play a central role in diagnosis and patient care, disease surveillance and control, and the provision of accurate health data for national planning and resource mobilization (WHO, 2015). Laboratory operations involve professionals from diverse backgrounds, including pathologists, laboratory analysts, managers, and supervisors, all of whom may assume managerial roles at different organizational levels (IFCC, 2010).

Turnaround time (TAT) for clinical chemistry and complete blood count testing is a key quality indicator used to evaluate laboratory performance (Gebreyes et al., 2020). Maintaining service quality is a continuous process that requires

teamwork, full staff engagement, and sustained efforts to improve performance. The establishment of laboratory turnaround time standards through ministerial regulations and accreditation frameworks is intended to ensure continuous quality improvement in hospital services. Accreditation of clinical laboratories encourages compliance with established standards, thereby ensuring service accountability and providing assurance and satisfaction to the public and laboratory service users regarding compliance with national quality benchmarks (Ministry of Health Decree No. 298/2008).

Turnaround time (TAT) challenges constitute a global phenomenon faced by healthcare systems worldwide, including Indonesia. This issue is complex and multidimensional, arising from various laboratory management dynamics such as inefficient queuing systems, imbalances between human resource capacity and specimen volume, and limitations of laboratory information systems that are not yet fully integrated (Ellison et al., 2018; Hawkins, 2007). Many hospitals in Indonesia continue to experience inconsistent achievement of clinical laboratory TAT targets. Delayed turnaround times can postpone clinical decision-making, reduce clinicians' work efficiency, and potentially increase patient risk. These delays are commonly attributed to inefficient queuing systems, prolonged waiting times, and workflow bottlenecks resulting from mismatches between staffing levels and specimen volumes, particularly during peak hours in pre-analytical processes such as registration, sample collection, and result verification (Syntax Literate, 2024).

In Indonesia, laboratory turnaround time is considered compliant with national standards when results are reported within ≤140 minutes, as stipulated in the Decree of the Minister of Health of the Republic of Indonesia No. 129/2008 on Hospital Minimum Service Standards. Laboratory waiting time is calculated from the moment a specimen is received in the laboratory until the laboratory result is printed and made available (Bhatt et al., 2019).

The total laboratory testing process is divided into three phases: pre-analytical, analytical, and post-analytical. The pre-analytical phase encompasses all activities performed prior to sample analysis, including test order entry by admission staff, patient identification, patient preparation, specimen collection, and specimen transport or storage. The analytical phase begins with the initiation of testing (actual testing) and continues until result confirmation. The final phase, post-analytical, involves result validation and verification by the laboratory supervisor, followed by result reporting and delivery to patients or referring clinicians, either electronically or through manual collection at the admission unit. Result validation is a critical step to ensure the accuracy and reliability of laboratory findings.

Resources are a fundamental component of medical service delivery; however, limited resources pose significant challenges for management in allocating and utilizing healthcare resources efficiently (Wu et al., 2020). Delays frequently occur when service demand fluctuates beyond available capacity. Suleiman et al. (2022) reported that patient frustration and dissatisfaction often arise when patients leave queues upon realizing that waiting times and service durations are excessively long.

Given that this study adopts an in-depth, descriptive-analytical approach aimed at mapping the dynamics and factors contributing to turnaround time (TAT) delays in clinical laboratory services, data collection was preceded by a preliminary study. This preliminary study was conducted randomly over a 10-day period from 7 to 16 August 2024 and involved 1,073 clinical chemistry blood specimens.

METHODS

Study Design

Based on the scope of the research problem, this study employed an observational design. Observational research involves the collection of both qualitative and quantitative data without any intervention on the study object. These data were analyzed to develop an evidence-based model that may serve as a solution to similar operational problems in healthcare settings (Supriyanto et al., 2022).

This study used a cross-sectional design, in which observations of the study variables were conducted within a single defined time period. A time and motion study approach was applied through direct observational surveys conducted without the awareness of laboratory personnel as study subjects. The time and motion study method was used to systematically evaluate service processes, with a primary focus on measuring and analyzing time utilization across laboratory workflow stages.

Population, Sample Size, and Sampling Technique

The study population comprised all blood specimens processed by the laboratory team, involving a total of 26 laboratory personnel. The inclusion criteria for this study were as follows:

1. Specimens collected by laboratory staff
2. Specimens obtained from outpatient clinics, medical check-up services, and inpatient units
3. Specimens subjected to clinical chemistry and complete blood count examinations
4. Specimens collected exclusively during the morning shift, between 07:00 and 14:00

RESULTS AND DISCUSSION

The study was conducted over eight observation days, with study dates randomly selected during April–May 2025 at the laboratory of Hospital X. The following section presents a summary of the number of respondents observed from the first through the eighth day of data collection.

Table 1 Number of Respondent Sampling based on Research Time April and May 2025 in the Laboratory of RS X

Day to (-) and Description		Number of Patients (n)	Percentage (%)
(1)	Thursday, 10 April 2025	125	13,2%
(2)	Monday, April 14, 2025	112	11,8%
(3)	Thursday, 17 April 2025	96	10,1%
(4)	Monday, April 21, 2025	98	10,3%
(5)	Thursday, 24 April 2025	106	11,2%
(6)	Tuesday 29 April 2025	99	10,4%
(7)	Tuesday, May 6, 2025	135	14,2%
(8)	Wednesday, 14 May 2025	177	18,7%
Total		948	100%

Table 1 presents the distribution of respondents by observation day during the eight days of data collection. Of the total 948 respondents, the highest number was recorded on the eighth day, with 177 patients (18.7%). This was followed by the seventh day with 135 respondents (14.2%) and the first day with 125 respondents (13.2%). On the second day, 112 respondents (11.8%) were recorded, followed by the fifth day with 106 respondents (11.2%). Meanwhile, the sixth day accounted for 99 respondents (10.4%), the fourth day for 98 respondents (10.3%), and the lowest number was observed on the third day, with 96 respondents (10.1%). Overall, an increasing trend in respondent numbers was observed at the beginning and the end of the study period, which may be attributed to the proximity of these dates to public holidays.

Identification of Patient-Related Factors

Of the total 984 patient specimens, detailed characterization of patients utilizing laboratory services was necessary to obtain a comprehensive profile of the study population. These characteristics included age, specimen condition, payment status, and specimen source. Understanding the distribution of these characteristics is essential, as they may influence service patterns, laboratory workload, and diagnostic workflow processes. Furthermore, the diversity of patient characteristics reflects the range of healthcare services accommodated by PHC Hospital. Table 2 presents the characteristics of patients who utilized laboratory services.

Table 2 Characteristics of Respondents' Conditions (Patient Specimens)

Variabel	Category	Number of Patients (n)	Percentage (%)
Age	<20 years old	97	10,2%
	21 – 40 years old	231	24,4%
	41 – 60 years old	323	34,1%
	>60 years old	297	31,3%
Patient Factors			
Specimen Condition	*Non-emergency*	948	100%
Payment Status	BPJS	528	55,7%
	General	190	20,0%
	Insurance/Company	230	24,3%
Specimen Source	Hospitalization	199	21,0%
	Outpatient	457	48,2%
	Medical Check Up	292	30,8%

Table 2 presents the distribution of respondents by age group among the total of 948 respondents. The largest proportion was observed in the 41–60-year age group, comprising 323 individuals (34.1%), followed by those aged over 60 years, with 297 individuals (31.3%). Meanwhile, 231 respondents (24.4%) were aged between 21 and 40 years, and the smallest proportion consisted of respondents under 20 years of age, totaling 97 individuals (10.2%). These findings indicate that the majority of respondents were adults to older adults, with the highest concentration in the 41–60-year age group.

Regarding specimen condition, all recorded specimens (948; 100%) were classified as non-emergency cases. In terms of payment status, patients covered by the national health insurance scheme (BPJS) accounted for 528 cases (55.7%), followed by self-paying (general) patients with 190 cases (20.0%), and patients covered by private insurance or corporate agreements with 230 cases (24.3%). With respect to specimen sources, outpatient services contributed the largest share, with 457 cases (48.2%), followed by medical check-up services with 292 cases (30.8%), while inpatient services accounted for the smallest proportion, with 199 cases (21.0%).

Overall, laboratory services at PHC Hospital were predominantly utilized by middle-aged to older adult patients (41–60 years), with the majority covered by BPJS insurance (55.7%) and originating from outpatient services (48.2%). These findings indicate that laboratory services at PHC Hospital primarily support the diagnostic needs of outpatients rather than inpatient care or routine medical check-up examinations.

Analysis of Average Service Time Across Clinical Laboratory Process Phases

When time measurements are recorded for each stage of the laboratory service process and the mean service time is calculated, varying durations are observed across different phases. These variations reflect differences in activity complexity and the workload encountered by laboratory personnel at each phase. The greater the complexity of activities at a given service point, the longer the time required to complete the process.

The objective of calculating average service time is to identify process stages that require attention and improvement. By determining the mean time spent at each service station, laboratory management can assess phase-specific efficiency, identify key bottlenecks, and develop more targeted strategies for workflow optimization.

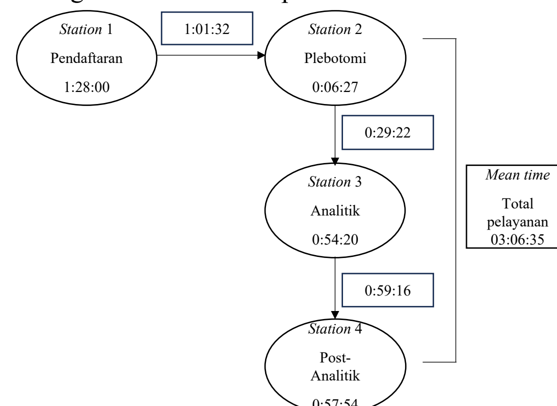

Figure 1 Average time spent in each service actually taken in the field during the 8 days of the research

Figure 1 illustrates that laboratory services in this study were organized into four main service stations. At the first station, registration, the average time required per patient was 1 hour and 28 minutes. The process then proceeded to the second station, phlebotomy, with an average duration of 6 minutes and 27 seconds. The transition time from registration to phlebotomy averaged 1 hour, 1 minute, and 32 seconds. Patients subsequently entered the third station, the analytical phase, which had an average processing time of 54 minutes and 20 seconds. The recorded waiting time between phlebotomy and the analytical phase was 29 minutes and 22 seconds. The final stage was the post-analytical station, with an average duration of 57 minutes and 54 seconds. The transition time from the analytical to the post-analytical phase averaged 59 minutes and 16 seconds.

This workflow represents the sequential stages of laboratory services, from administrative procedures to result validation, with the total service time reflecting overall laboratory performance. Accordingly, the average total laboratory service time was 3 hours, 6 minutes, and 35 seconds (186.6 minutes) given the staffing levels available during the study period. This duration exceeded the established Turnaround Time (TAT) standard of less than 140 minutes.

Overview of Turnaround Time

Turnaround Time (TAT) is defined as the total time required from patient registration to the receipt of laboratory test results by the patient or referring physician. This indicator serves as a primary measure of laboratory service quality, as it

is directly associated with patient satisfaction, the timeliness of clinical decision-making, and the overall effectiveness of hospital services. In this study, the TAT benchmark applied was <140 minutes, in accordance with clinical laboratory service quality standards.

Table 3 Overview of *Turnaround Time* in the PHC Hospital Laboratory in the April and May 2025 Research for 8 Days

Variable	Category	Total (n)	Presentase (%)
Turnaround Time (TAT)	Inappropriate	534	56.3
	Conform	414	43.7
	Total	948	100

Based on table 3, it is known that out of a total of 948 samples, there were 534 samples (56.3%) that had non-standard TAT, while only 414 samples (43.7%) had non-standard TAT. This shows that more than half of the laboratory services have not met the set TAT standards.

Analysis of the Influence on Laboratory Service Process Time on Turnaround Time

The influence of the service flow on TAT was analyzed based on each service station, starting from the registration process to phlebotomy. The analysis focused on the difference in the proportion of services that exceeded the standard time (>140 minutes) compared to timely services (≤140 minutes). Here's a statistical test using Chi-Square:

Table 4 Analysis of the Influence of Each Station in Service Time at the PHC Laboratory from April to May 2025 for 8 Research Days

Station	Time Period	TAT				Chi-Square (p)
		Inaccurate (>140 minutes)		Precise (≤140 minutes)		
		n	%	n	%	
1 Registration	00.00 – 02.59	41	64	23	36	0.000
	03.00 – 05.59	14	93,3	1	6,7	
	06.00 – 08.59	312	60,1	207	39,9	
	09.00 – 11.59	154	52,6	139	47,4	
	12.00 – 14.59	13	22,8	44	77,2	
2 Sandflies	06.00 – 08.59	316	52,1	290	47,9	0.004
	09.00 – 11.59	212	64,2	118	35,8	
	12.00 – 14.59	4	40	6	60	
	15.00 – 17.59	1	100	0	0	
	21.00 – 23.59	1	100	0	0	
3 Analytics	00.00 – 02.59	60	73,2	22	26,8	0.000
	03.00 – 05.59	6	85,7	1	12,5	
	06.00 –	79	32,6	163	67,4	

Station	Time Period	TAT				Chi-Square (p)
		Inaccurate (>140 minutes)		Precise (≤140 minutes)		
		n	%	n	%	
	08.59					
	09.00 – 11.59	319	63,4	184	36,6	
	12.00 – 14.59	68	61,3	43	38,7	
	15.00 – 17.59	1	100	0	0	
	21.00 – 23.59	1	100	0	0	
4 Post-Analytics / Results Submission	00.00 – 02.59	77	57,9	56	42,1	0.000
	03.00 – 05.59	97	86,6	15	13,4	
	06.00 – 08.59	62	48,8	65	51,2	
	09.00 – 11.59	127	37,8	209	62,2	
	12.00 – 14.59	133	44,3	67	22,3	
	15.00 – 17.59	36	94,7	2	5,3	
	18.00 – 20.59	1	100	0	0	
	21.00 – 23.59	1	100	0	0	

Table 4 explains that there is a real influence on the timeliness of laboratory services at each station based on a certain period of time. At the registration station, the most frequent delays occurred in the morning, especially at 03.00–05.59 with 93.3%, the flebotomime station, the largest delays were recorded at 09.00–11.59 with 64.2% of untimely checks, analytical stations at 03:00 – 05:59 were 85.7% and post-analytical stations were dominant at 15:00 – 17:59 at 94.7%.

Based on the results of the Chi-Square test, an overview of the effect of the level of service timeliness (Turnaround Time / TAT) on each station in the laboratory, namely registration, phlebotomy, analytics, and post-analytics, namely:

1. Station Registration

The test results showed a value of p = 0.000, which means that there was a significant relationship between the service time period and the timeliness of completion. The highest percentage of punctuality occurred in the period 12:00–14:59, which was 77.2%, while the lowest accuracy was seen in the period 03:00–05:59, which was only 6.7%. This condition illustrates that services during the day are more efficient than in the early morning. In the period 06.00–11.59, which is the peak patient hours, an increase in the number of patients with inappropriate TAT (>140 minutes) was seen, indicating a queue buildup due to the high registration burden during the main operating hours.

2. Station Flebotomi

In the phlebotomy station, a value of p = 0.004 was obtained, which means that there is a significant relationship between the service time and the accuracy of the TAT. The highest punctuality occurred in the period 12.00–14.59 at 77.2%, while the lowest occurred in the period 09.00–11.59 with an accuracy level of 35.8%. This shows that the implementation of sampling during peak patient

hours tends to cause delays. On the other hand, during the afternoon to evening hours, the sampling process can be carried out faster because the workload of phlebotomists begins to decrease.

3. Station Analitik

Station analytics also showed a statistically significant relationship with a value of p = 0.000. The highest percentage of accuracy occurred in the period 06.00–08.59 of 67.4%, while the lowest accuracy was in the period of 00.00–02.59 of 26.8%. These findings suggest that at the beginning of operational hours, the analytical process is more efficient because the sample flow is already organized from the previous phase. However, in the evening until the early morning, the inspection process was delayed due to limited manpower, shift transition time, and urgent inspection priority.

4. Station Post-Analitik

In the post-analytical phase or submission of results, the value of p = 0.000 shows a significant relationship between the time period and the accuracy of the TAT. The highest punctuality was achieved in the period 06.00–08.59 by 51.2% and 09.00–11.59 by 69.2%, while the lowest accuracy was seen in the period 03.00–05.59 by 13.4% and 15.00–17.59 by 5.3%. This condition shows that the morning time is the most productive period in the submission of results, as laboratory administrative activities increase. Meanwhile, in the afternoon to evening, the activity of reporting results decreased due to the limited administrative officers and the operational time of accepting new patients.

Patient Satisfaction Identification Results

In this study, interviews were conducted with 397 respondents who were willing to participate in the assessment of the level of satisfaction with laboratory services. This satisfaction identification aims to assess the ability of laboratory services to meet patient expectations in various aspects, especially related to *turnaround time*, quality of service provided by officers, accessibility of information delivered, and comfort during the examination process. Here are the results of the satisfaction assessment:

Table 5 Patient Satisfaction Identification Results

No	**Indicator**	**Amount of Dissatisfaction** (a)	**Total Satisfaction** (b)	**Satisfaction Percentage** ($\frac{b}{(b+a)} x 1$)	**Category**
A	*Accesibility*				
1	Officers can be contacted when needed	0	397	100%	Very satisfied
2	Communication between patients and staff	0	397	100%	Very satisfied
3	The staff is always helpful if there is a problem	10	387	97,5%	Very satisfied
B	Information Providers				
1	Test information available in the Laboratory	173	224	56,4%	Dissatisfied
2	Information about the clinical use of each test	235	162	40,8%	Dissatisfied

No	Indicator	Amount of Dissatisfaction (a)	Total Satisfaction (b)	Satisfaction Percentage ($\frac{b}{(b+a)} x 1$)	Category
3	Sampling instructions information	157	240	60,5%	Dissatisfied
4	Information on how to package samples for transport from patients to laboratories	268	129	32,5%	Dissatisfied
5	Information on how to report results	27	370	93,2%	Very satisfied
6	Time of receipt of results	7	390	98,2%	Very satisfied
7	Request clarity in forms	14	383	96,5%	Very satisfied
8	Completeness of the request for required clinical information	13	384	96,7%	Very satisfied
9	Answers to additional questions about laboratory testing requests	12	385	97%	Very satisfied
10	Clarity of the final result	12	385	97%	Very satisfied
C	Service Providers				
1	Laboratory can perform necessary examinations	3	394	99,2%	Very satisfied
2	Laboratory can perform necessary examinations	4	393	99%	Very satisfied
3	The average wait time for	13	384	96,7%	Very satisfied

No	Indicator	Amount of Dissatisfaction (a)	Total Satisfaction (b)	Satisfaction Percentage ($\frac{b}{(b+a)} x 1$)	Category
	receipt of laboratory results is quite short				
4	Completion time in the laboratory	3	394	99,2%	Very satisfied
5	The staff is always courteous during contact with the patient	0	397	100%	Very satisfied
6	Officers always help patients	0	397	100%	Very satisfied
7	The officers are always professional	0	397	100%	Very satisfied
8	The officers are always professional	0	397	100%	Very satisfied
9	Satisfaction with laboratory services in general	0	397	100%	Very satisfied
10	Satisfaction with the staff in the laboratory	0	397	100%	Very satisfied

Table 5 shows that from a total of 397 patients who have accessed laboratory services and are willing to be interviewed, an overview of the level of patient satisfaction with various service indicators is obtained. In terms of accessibility, all indicators received a very satisfactory assessment. Patients assessed that the laboratory staff could be contacted when needed (100%, very satisfied), the patient's communication with the staff went well (100%, very satisfied), and the staff always helped if there was a problem (97.5%, very satisfied). This shows that laboratory services are accessible, fast, and responsive.

The information provider component shows mixed results. Several indicators obtained high scores, such as information on how to report results (93.2%, very satisfied), time of receipt of results (98.2%, very satisfied), clarity of requests in forms (96.5%, very satisfied), completeness of clinical information requests (96.7%, very satisfied), answers to additional questions (97%, very satisfied), and clarity of final results (97%, very satisfied). However, there were several indicators with low scores, namely test information available in the laboratory (56.4%, dissatisfied), information about the clinical use of each test (40.8%, dissatisfied), information on sampling instructions

(60.5%, dissatisfied), and information on how to package the sample (32.5%, dissatisfied). This confirms that although most information services are clear, the technical education and clinical information aspects are still major weaknesses that need to be fixed.

In terms of service providers, all indicators are in the category of very satisfied. The laboratory was considered to be able to perform the necessary examinations (99.2%, very satisfied), have sufficient capacity to accommodate requests (99%, very satisfied), provide a short waiting time for results (96.7%, very satisfied), complete the examination quickly (99.2%, very satisfied), and the officers are always polite (100%, very satisfied), help patients (100%, very satisfied), professional (100%, very satisfied), friendly (100%, very satisfied), and provide generally satisfactory service (100%, very satisfied). This high level of satisfaction describes the consistent and excellent quality of service.

Overall, the results show that accessibility and service providers are at a very high level of satisfaction, indicating friendly, fast, and professional service. However, the information provider aspect is still a significant weak point, especially related to patient education regarding laboratory tests, clinical utilization, and technical procedures. Therefore, although in general the quality of laboratory services is considered very good, improvements in the information aspect remain a priority to ensure more comprehensive and transparent services.

DISCUSSION

Queue density

The overall pre-analytical, analytical and post analytics graphs show that the peak of laboratory patient arrivals recorded took place evenly, sequentially, and in accordance with the flow of the service process. The peak of laboratory patient arrivals was recorded as pre-analytical occurring evenly, sequentially and in accordance with the course of the process, namely the first density in pre-analytics starting at 06.00-08.59 was carried out at registration and blood collection. Then entering the analytical phase, there began to be queues at 06.00-08.59, then the density increased briefly entering 09:00 – 11:59, and the same thing with post-analytical density at the same time, namely 09:00 – 11:59. This phenomenon was consistent almost throughout the eight days of observation, showing regularity in the flow of the laboratory service process

The regularity of density flows is in accordance with the concept *of flow dependencies*. The queue in pre-analytics moves to the analytics phase, then continues to the post-analytics phase, following the sequence of the laboratory service flow. Thus, the resulting density does not stand alone, but rather is a chain consequence of the patient's load in the previous phase. This shows that the service flow system has run in accordance with the principle of the service process chain even though there is an influence on the level of density at certain hours. Delays or inconsistencies in the initial phase will have a domino effect in the later phases.

In the pre-analytic density that occurred at 06:00 – 08:59, this queue distribution time reflected the tendency of patients to choose the time of the morning when accessing laboratory services due to the need for routine check-ups (such as fasting before blood tests). According to research by Zhang *et al*. (2017) A similar thing happened in Chinese hospitals, 70–80% of laboratory patient arrivals occurred before 11:00 a.m., with a peak at 7:00 a.m.–9:00 a.m. The accumulation of patients at this particular time is greatly influenced by the patient's habits, limited working time, and medical recommendations (e.g. blood sampling in the morning for accuracy of results). Lee *et al*. (2022) in South Korea found that 74.1% of total laboratory visits were concentrated between 06.00–10.00, leading to long queues, long wait times, and potential over-crowding at service facilities. Similar conditions were also reported by Risch *et al*. (2021) in Switzerland, where the accumulation of patients in the morning is a major challenge in the management of human resources and laboratory equipment, as staff have to work more intensively in a short period of time, while at other hours it is relatively loose.

After pre-analysis, all samples will enter the analytical process at the highest hours at 09:00 – 11:59. In the workload analytics phase, it follows a pre-analytical peak pattern. The results showed that the spike in analytical load usually follows the pre-analytical patient arrival curve, with a slight time delay due to the time of sampling and sending samples to the analytical tool. Hawkins (2012) and Sciacovelli *et al*. (2017) mentions that the workload imbalance between pre-analytics and analytics is often a source of *bottlenecks* in the laboratory. If too

many samples come in at the same time due to pre-analytical density, analytical tools and HR can be *overloaded*, causing longer service times and increased error potential. The impact is that the turnaround time (TAT) of laboratory results has also increased. Simundic *et al*. (2015) emphasized that the best solution is to spread the patient's arrival time and optimize resources at peak hours, so that the distribution of samples to analytics is more evenly distributed and the processing time can be kept short (Simundic, A. M., *et al*. (2015).

The density graph in post-analytics is high at 9:00 a.m. – 11:00 a.m. and then tends to decrease after the analytical peak (generally during the day), but on certain days there is still a high spike, e.g. 12:00 p.m. – 2:59 p.m. (day 8: 42 results, day 5: 38 results). The research conducted by Sciacovelli *et al*. (2017) and Barbui *et al*. (2021) stated that the optimal wait time on post-analytics for validation & reporting is in the range of 20–30 minutes per result in a hospital laboratory with manual processes, especially during peak hours and a workload of 1 officer for 12–15 results/hour during peak hours and the officer is not multitasking with other administrative tasks. Barbui *et al*. (2021) stated that if the post-analytics workload is consistent above 15 results/hour, there should be additional officers or reporting automation to maintain the quality and speed of services.

Lippi *et al*. (2011) stated that the success of the laboratory is highly dependent on cross-phase synergy, from registration to reporting results. Any *bottlenecks* in one of the phases will have an impact on the overall efficiency of the system. The balance of workload and capacity in each phase is critical to maintaining the turnaround time of laboratory results and improving patient and clinician satisfaction.

Pace of Service in the Laboratory

The results of the calculation of the rate of patient arrival in each phase of laboratory services show the influence of the inter-phase workload pattern. The pre-analytical phase is the most congested point in the laboratory service flow because at this stage all patients first enter the system through the registration and sampling process. High density in this phase requires optimal control of resources, both in terms of the number of officers, readiness of tools, technology and the regularity of workflows. Any delays or procedural inconsistencies in pre-analytics will have a chain effect on the next phase, making time management and workload distribution a crucial aspect.

First, in the pre-analytical phase, there were two main stations observed, namely *station* 1 (registration) and *station* 2 (phlebotomy). *Station* 1 (registration), peak hours occur at 06.00–08.59, with an average arrival rate of 18.8 samples per hour. This figure reflects that most patients choose to come in the morning, so the queues at the registration counter accumulate during that time range. With only two registration officers available, the workload at this station is relatively high, especially since each registration process involves validating identity data, input into the system, and recording laboratory examination requests.

Meanwhile, station 2 (phlebotomy) which is the blood sampling stage also shows a peak pattern at the same time, namely 06.00–08.59, with an average ability to serve 25.88 samples per hour. The workload at this stage is handled by three phlebotomy officers, each of whom is in charge of carrying out sampling procedures according to operational standards. The high average number of samples that can be served in one hour shows that the service capacity at the phlebotomy station is greater than the registration. Based on calculations, there are more phlebotomy officers but blood collection procedures can be carried out in parallel on several patients at the same time unlike in registration.

Meanwhile, in the analytics and post-analytics phases, workloads tend to decrease. However, these two phases still require a high level of precision so that the results of the examination can be ensured of their validity and accuracy. In the analytics phase, minor glitches such as errors in the tool can cause significant delays. In the analytical phase, which took place at 09.00–11.59, the average arrival rate was recorded at 20.9 samples per hour. This figure is relatively lower compared to the pre-analytical phase. In the analytical phase, almost all work is done by automated inspection tools or machines. The pre-processed sample is fed into the machine for analysis based on the required examination parameters. This shows that the performance in this phase is more reflective of the capacity and ability of the machine to analyze the specimen, rather than the manual involvement of the implementer. Therefore, delays or inconsistencies that occur in the analytical phase are generally not caused by individual factors, but are more related to technological readiness, machine speed, availability

of reagents, and equipment maintenance systems. The analytical phase is a point that emphasizes technology in supporting laboratory quality.

Entering the post-analytical phase, service density was recorded in the same time period as the previous phase, namely 09.00–11.59. In this phase, the average sample arrival rate is lower, which is 15.9 samples per hour. Although the number is smaller, the responsibility is enormous because it concerns the validation of results, reporting, and distribution to doctors and patients. Any errors or delays at this stage will directly affect the overall clinical service. This can be explained because only samples that have been completed through the analytical process then enter the validation, reporting, and distribution stages of results. Thus, the more advanced the service phase, the number of samples managed tends to decrease along with the process of screening, settling, and eliminating samples in the previous stages.

For the number of officers, the value of the relatively low arrival rate in the post-analytical phase was influenced by the number of officers. Unlike other stations such as registration which has two admission officers or phlebotomy which is handled by three officers, but post-analysis the entire validation process and reporting results are only carried out by one officer. Conditions like this make the capacity to handle samples in the post-analytical phase more limited than in the pre-analytical and analytical phases. Although the number of incoming samples is indeed less, the existence of only one officer is still an important factor that can affect the smooth process of distributing results, especially during peak hours.

Thus, it can be concluded that the largest workload does occur in the pre-analytical phase. A high spike in workload in this phase is often the starting point for delays and requires an effective resource control strategy. However, although pre-analytics is the most congested point, the overall quality of laboratory services is not only determined by this initial phase and laboratory services remain highly dependent on prudence and accuracy in the analytical and post-analytical phases.

The three phases cannot be separated because they complement each other and form a quality chain of laboratory services. Therefore, the success of *Turnaround Time* (TAT) and patient satisfaction is largely determined by the harmonious coordination between these three phases. With good management at every stage, laboratories can achieve efficient, accurate, and high-standard services, so as to be able to support appropriate clinical decisions and improve the overall quality of hospital services.

According to CLSI (Clinical and Laboratory Standards Institute) H3-A6 standards and international studies, the ideal ratio of 1 administrative officer (registration/pre-analytics) is 15–20 patients per hour to ensure <10 minutes of registration waiting time and efficient process. In line with previous research put forward by Barbui *et al* (2021), it is said to be normal to serve 15-20 patients / hour during peak hours. The ratio is set to ensure that the registration waiting time is less than ten minutes so that the process can run efficiently and the flow of services is maintained. In the context of this study, observations are only focused on the clinical chemistry service process, so that the calculation of the workload of the implementing staff is more specific in that scope. However, when the total number of services (clinical chemistry, immunology, hematology and serology) in the laboratory is calculated, the officers become *overloaded* in their work.

IFCC establishes post-analytical quality indicators (QI) such as the timeliness of results reports as the main KPIs of the laboratory (Plebani *et al*., 2016). The lower λ in post-analytics is in line with the function of this phase as downstream (validation, reporting, distribution of results). Although the volume is smaller, the IFCC quality indicator (QI) standard places *timeliness* and post-analytical errors as important control areas as small improvements in this phase that often have a major impact on clinical TAT.

Average Time of Service in the Laboratory

When calculated based on the average value of service time in the laboratory by taking into account the number of available officers, it can be concluded that the service ability is longer than the ideal time. The length of time shows that the workload of the officers has not been balanced with the number of patients served, so that service efficiency has not been achieved according to the ideal Turnaround Time (TAT) standard, which is less than 140 minutes.

If you look at each phase, Station 1 (registration) occupies the longest time, which is 1 hour 28 minutes (1:28:00). The long time in this phase shows that the registration service point is the main contributing factor to the length of the total waiting time. These results are in line with the research of Barba *et al*. (2018) which found that the

administrative and pre-analytical phases are the largest contributors to laboratory process delays, especially during peak hours, when the capacity of the staff is not proportional to the volume of patients who arrive.

Furthermore, Station 2 (plebotomi) has an average service time of 6 minutes 27 seconds (0:06:27), with the average waiting time between processes to the next stage being 1 hour 1 minute 32 seconds (1:01:32). This indicates that although the sampling process is relatively fast, the waiting time between phases is still quite long. This delay can be caused by the sampling queue or the process of distributing specimens to the analytical room. These findings are reinforced by the research of Sciacovelli *et al*. (2019) which states that *sample workflow management* and distribution speed are the main determinants of efficiency in the pre-analytical and early analytical phases.

However, in Station 3 (analytics), the average time spent was 54 minutes 20 seconds (0:54:20), while the lag time between the previous phases (from plebottomy to analytics) reached 29 minutes 22 seconds (0:29:22). This shows that the time of the analytical process is relatively efficient, in line with the implementation of automation systems and the use of high-tech equipment. These results are in line with the research of Plebani (2006) which states that although the proportion of errors and delays in the analytical phase is relatively small (about 10–15% of the total), the accumulated time from the pre-analytical phase can significantly extend the total TAT.

Meanwhile, tation 4 (post-analytics) showed an average time of 57 minutes 54 seconds (0:57:54) with the average pause time before this process began was 59 minutes 16 seconds (0:59:16). The length of time in this phase shows that the result validation process is still a major challenge in the efficiency of laboratory services. Research by Carraro and Plebani (2019) states that the post-analytical phase is the second largest contributor to delays after the pre-analytical phase, mainly due to manual verification processes, delays in certifying results, and laboratory information system constraints.

Overall, the results of this study show that the greatest time burden in laboratory services is in the registration phase and the longest waiting time occurs in the transfer from Station 1 (registration) to Station 2 (plebotomi), with an average duration of 1 hour 1 minute 32 seconds. The length of this queue time indicates that there is a build-up of patients in the sampling area due to the speed of service at registration which is not proportional to the service capacity at the next stage. This condition shows that the flow of patients between stations has not been balanced, causing cumulative delays in the entire laboratory service process.

Then calculations are carried out with the aim of determining the gold standard as a basic reference for services in the laboratory. The calculation results showed that the registration phase (pre-analytics) took an average of 44 minutes This duration was the longest phase compared to other stages, which indicates that administrative processes such as data input, verification of examination requests, and printing of specimen labels are high points of workload. Furthermore, the specimen collection phase (plebotomy) takes an average of 1 minute, which is the shortest time in the service. It can be seen with a short time measure like this illustrates that there should be no failure of blood collection. Then 43 minutes in analytics depending on the analytics tool, and the trailer in post-analytics at 22 minutes. If the officer is able to perform services within the time limit, he will get optimal service.

***Turnaround Time* (TAT) Clinical Chemistry Laboratory Examination**

It is known that out of a total of 948 samples, there were 534 samples (56.3%) with *a Turnaround Time* (TAT) that was not in accordance with the standard (<140 minutes), while only 414 samples (43.7%) met the TAT standard. These results show that the performance achievement of the PHC Hospital laboratory in meeting the TAT standard is still very low, because more than half of the laboratory services are not in accordance with the set value. In clinical laboratory accreditation standards, the TAT indicator is the main benchmark of service quality because it relates to diagnostic speed and clinical decision-making. The TAT value of <140 minutes is generally used as an international reference for education and referral type hospital laboratories (Plebani, 2017). With an achievement of only 43.7%, this performance can be categorized far below the accreditation standard.

These findings are in line with the research of Alsharif *et al*. (2019) at a referral hospital in Saudi Arabia that reported TAT compliance at only about 48%, indicating that low TAT achievement is a global problem in hospitals with high patient burdens. A similar condition was also found by

Plebani (2018) who emphasized that more than 50% of hospital laboratories in Europe face difficulties in achieving the TAT target due to limited human resources, excessive workload, and information system constraints.

However, these results differ from the research of Lippi *et al*. (2017) which reported that laboratories in several major Italian hospitals were able to achieve TAT compliance above 80% after implementing full automation systems and real-time monitoring. This influence shows that the achievement of TAT is greatly influenced by infrastructure readiness, supply chain management, and an integrated laboratory quality system.

Thus, the achievement of TAT at PHC Hospitals which is still below accreditation standards needs to be a serious concern. Improvement interventions can be focused on pre-analytical optimization (registration and sampling), analytical process efficiency (automation and validation), and post-analytics acceleration (verification and reporting of results). Real-time *Laboratory Information System* (LIS)-based monitoring is also important to ensure compliance with TAT standards.

The Effect of Process Time at Each Phase in the Laboratory Service Process on Turnaround Time

All service stations (registration, phlebotomy, analytics, and post-analytics/submission of results) showed a significant relationship with Turnaround Time (TAT) in the chi-square test (p=0.000). These findings indicate that the variation in service time that exceeds the standard of 140 minutes is influenced by the peak hours at each station. Thus, service time has been proven to be a factor that affects the speed of completion of the overall laboratory examination. Services that exceed the standard of 140 minutes are mainly affected by peak hours conditions at each station, where increased patient volumes lead to higher workloads and potentially cause delays. Thus, each phase in the laboratory service flow has a contribution to the achievement of TAT, although the intensity of its influence may differ between stations.

At registration stations and phlebotomi, the highest percentage of inaccuracies occurred during peak hours, namely 60.1% and 64.2% from 06.00–08.59 a.m. These findings are in line with the research of Barba *et al*. (2018) which states that peak *hours* in the pre-analytical phase are one of the main causes of TAT delays due to an imbalance between officer capacity and the number of patients. The study also confirms that the ideal ratio of administrative officers is one officer to serve 15-20 patients per hour so that the waiting time does not exceed 10 minutes. In line with international reports that 46–68% of laboratory errors occur in the pre-analytical stage, especially during registration and sampling (Plebani, 2017; Sciacovelli *et al*., 2019).

However, in analytics and post analytics, there is the highest inaccuracy at 03:00 – 05:59 which is not active service hours. Meanwhile, the highest accuracy occurs in the morning or during the active hours of the officer's completeness, namely at 06:00 – 08:59 for analytics and 09:00 – 11:59 for post analytics. This shows that the reporting of laboratory test results runs more efficiently during key operating hours, while delays tend to increase outside of normal working hours. These findings are in line with the research of Da Rin (2019) who also mentioned that delays often appear during peak hours when the patient load increases, especially if the resource capacity is not balanced with the number of incoming samples.

The morning to noon period (06.00–11.59) is the time with the highest risk of delays due to the increasing volume of patients and limited human resource capacity. These findings are in line with the results of the research of Sciacovelli *et al*. (2019) which states that the unbalanced distribution of service time is one of the main determinants of TAT delay, especially if it is not balanced with an efficient workflow management-based work system.

Therefore, laboratory management needs to implement data-based service optimization strategies, such as patient scheduling based on time slot scheduling, adding officers at peak hours, and automating sample distribution between stations. Several studies that have been conducted by Plebani (2006) and Carraro & Plebani (2019), show that the application of this strategy has been proven to be able to reduce TAT variation and significantly increase the efficiency of laboratory work. Sciacovelli *et al*. (2017) emphasized that laboratory quality indicators must consider the burden of service time, because the influence of workload distribution between periods can directly affect the consistency of TAT.

CONCLUSION

The development of Lundberg's theory, which was originally descriptive, became a

quantitative analytical framework to improve the analysis of laboratory service flows. *Lundberg's 9 Step Workflow theory* provides a comprehensive overview of the stages of laboratory examination and emphasizes the interconnectedness between processes and potential clinical errors in the *brain-to-brain loop*. With a time motion study on Lundberg's theory, it can describe the actual time to find out the time of laboratory services that have been used, so that hospitals can make the right decisions to speed up services, reduce patient waiting times, and improve TAT achievement according to standards.

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