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Original Article

Cost analysis in the clinical chemistry laboratory in the era of automation: A prospective observational study.

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Abstract
Background
By standardizing the entire testing procedure and minimizing repetitive operations that could result in human mistakes, laboratory automation systems were created to enhance laboratory performance. To deliver high-quality services at a reasonable cost in the modern day, clinical laboratory administration surely depends on sound financial management.

Objectives
By comparing important metrics like turnaround time, test volume, labor cost, reagent waste, and maintenance expenses before and after automation, the study aims to assess how laboratory automation affects operational efficiency and cost parameters in a clinical chemistry laboratory.

Materials and Methods
It was a prospective, observational study. The study was carried out at the Patna Medical College and Hospital (PMCH), Patna, Bihar, India. The study was conducted for 12 months, i.e., from August 2024 to July 2025. In all, 150 patients were enrolled in the study. Participants had to be at least eighteen years old, have clinical specimens processed by PMCH's clinical chemistry laboratory throughout the study period, and have given their informed consent for participation and the use of anonymised data.

Results
The mean age of participants was 45.8 ± 13.4 years (pre-automation) and 46.5 ± 12.7 years (post-automation). Males constituted 56.0% of the pre-automation group and 53.3% of the post-automation group. Average tests per patient increased from 6.6 to 8.5 following automation. Monthly labor cost decreased from ₹4,00,000 to ₹2,60,000, and reagent wastage declined from 18% to 7%.

Conclusion
Automation significantly improved operational efficiency, reduced labor costs, increased test throughput, and minimized reagent waste.

Recommendation
Adoption of laboratory automation is recommended for tertiary-care laboratories to improve cost-effectiveness and workflow efficiency.

Keywords: *Laboratory Automation, Clinical Chemistry, Cost-analysis, reagent wastage, operational cost*
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Introduction
Creating high-quality, repeatable results from all clinical specimens received in the lab to the satisfaction of the end users that is, the patients and the clinicians is the main task of all clinical chemistry labs. The number of parameters being examined in all laboratories has skyrocketed due to

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the growing emphasis on diagnostic services to provide a wide range of biomarkers. The establishment's resources are severely strained by the cost of new procedures, testing, maintaining quality control, paying employees, paying utilities and overheads, and purchasing equipment and accessories for the clinical laboratories. There is a dispute about the growing expense of healthcare due to the proliferation of diagnostic modalities, which has prompted attempts to assess the effectiveness, safety, affordability, and societal advantages of medical technology. Depending on their costs and the laboratory's performance, the patient, as the final user, can also choose which facility to utilize for testing [1].

Since it affects every area of the laboratory, including selecting the best technique for conducting tests and producing high-quality reports, financial management is a crucial component of laboratory administration. An organization can function effectively if its financial policy is sound [2].

To help doctors and other healthcare professionals diagnose and treat patients more accurately, clinical chemistry is a multidisciplinary field that combines chemistry, biochemistry, immunochemistry, endocrinology, toxicology (both therapeutic and abused drug testing), analytical chemistry, engineering, informatics, and probably other specialties [3].

By standardizing the entire testing procedure and minimizing repetitive operations that could result in human mistakes, laboratory automation systems were created to enhance laboratory performance. Pre-analytical modules, task-targeted automation (TTA), and total laboratory automation (TLA) systems are among the many types of laboratory automation systems [4].

To deliver high-quality services at a reasonable cost in the modern day, clinical laboratory administration surely depends on sound financial management [2]. A clinical laboratory can benefit from cost analysis by using it as a tool to improve management efficiency and create a policy that works for future laboratory services [5, 6].

By comparing important metrics like turnaround time, test volume, labor cost, reagent waste, and maintenance expenses before and after automation, the study aims to assess how laboratory automation affects operational efficiency and cost parameters in a clinical chemistry laboratory.

Methodology

Study Design

It was a prospective, observational, cross-sectional study. The study was carried out at the Patna Medical College and Hospital (PMCH), Patna, Bihar, India. PMCH is one of the oldest and largest tertiary-care government hospitals in Eastern India, catering to both urban and semi-urban populations, with a high-volume central laboratory equipped with automated analyzers. The study was conducted for 12 months, i.e., from July 2024 to June 2025.

Study Population

In all, 150 patients were enrolled in the study. Participants had to be at least eighteen years old, have clinical specimens processed by PMCH's clinical chemistry laboratory throughout the study period, and have given their informed consent for participation and the use of anonymised data. Patients under the age of eighteen, those whose samples were handled in emergency or stat lab settings, those with incomplete or poorly labeled specimens, and those whose laboratory data were missing or inconsistent in hospital records were also excluded.

Sampling Technique

Participants were selected using consecutive sampling, where all eligible patients whose samples were processed during the defined pre-automation and post-automation phases were included.

Study Size

Sample size of 150 patients (75 per phase) was determined based on feasibility and the average monthly test load of the laboratory. This size was adequate to compare operational parameters (test volume, turnaround time, labor cost, reagent waste) before and after automation within the available timeframe and resources.

Data Collection

From patient files, demographic information, the reason for admission, and clinical indications were noted. Laboratory records and financial reports were used to capture laboratory data, such as the number of tests performed on each patient, turnaround time, monthly labor cost, percentage of reagent waste, and annual maintenance cost.

Bias Management minimized selection bias

All eligible consecutive cases were included. Measurement bias was reduced by applying standardized data extraction protocols for both pre- and post-automation phases. Observer bias was limited by involving independent laboratory personnel in data verification.

Ethical consideration

The study was approved by the committee

Statistical Analysis

Data were initially entered in Microsoft Excel. The data has been presented as either the number of participants (n) with percentages (%) or the mean with standard deviation (SD).

Results

A total of 176 patients were screened for inclusion in the study. Among them, 162 patients met eligibility criteria. Twelve patients declined participation.
Finally, 150 participants were enrolled and analyzed:

1. Pre-automation phase: 75 participants
2. Post-automation phase: 75 participants

All 150 participants completed the study, and no data were excluded from analysis.

Participants' ages were 45.8 ± 13.4 years in the pre-automation group and 46.5 ± 12.7 years in the post-automation group. There were 42 males (56.0%) and 33 females (44.0%) in the pre-automation group and 40 males (53.3%) and 35 females (46.7%) in the post-automation group. Of the patients in the pre-automation group, 27 (36.0%) were outpatients, and 48 (64.0%) were hospitalized as inpatients. A comparison of the clinical and demographic traits of individuals before and after automation is shown in Table 1.

Table 1. Comparison of Demographic and Clinical Characteristics of Participants in Pre- and Post-Automation Phases

Characteristic	Pre-Automation (n = 75)	Post-Automation (n = 75)
Age (in years)	45.8 ± 13.4	46.5 ± 12.7
Male	42 (56.0%)	40 (53.3%)
Female	33 (44.0%)	35 (46.7%)
Type of Admission, n (%)		
Inpatient	48 (64.0%)	51 (68.0%)
Outpatient	27 (36.0%)	24 (32.0%)
Common Indications, n (%)		
Routine health check-up	21 (28.0%)	20 (26.7%)
Diabetes/Metabolic disorder	19 (25.3%)	22 (29.3%)
Liver/Renal disease	15 (20.0%)	17 (22.7%)
Cardiovascular disease	11 (14.7%)	10 (13.3%)
Others	9 (12.0%)	6 (8.0%)

Before automation, the average number of tests per patient was 6.6; after automation, this number rose to 8.5. The labor-saving advantages of automated systems were demonstrated by the observed decrease in monthly labor costs, which went from ₹4,00,000 to ₹2,60,000. Reagent waste was also decreased from 18% to 7%. Laboratory performance and cost characteristics before and after automation are shown in Table 2.

Tale 2. Laboratory Performance and Cost Parameters in Pre- and Post-Automation Phases

Parameters	Pre-Automation	Post-Automation
Average Tests per Patient	6.6	8.5
Turnaround Time (hours)	4.6	2.1
Labor Cost (monthly)	₹4,00,000	₹2,60,000
Reagent Wastage (%)	18%	7%
Maintenance Cost (annual)	₹80,000	₹1,50,000

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Discussion

This study evaluated the impact of automation on the performance and cost structure of a clinical chemistry laboratory. Automation resulted in a higher number of tests performed per patient, shorter turnaround times, reduced monthly labor costs, and significantly lower reagent wastage. These improvements indicate that automation strengthened both efficiency and resource utilization within the laboratory. The increase in testing capacity following automation suggests improved workflow continuity and reduced manual handling, leading to faster processing of samples. The reduction in labor cost reflects decreased dependence on manual operations, allowing redistribution of staff to more specialized tasks. The marked decline in reagent wastage highlights the precision of automated dispensing systems and reduced pre-analytical errors. Although maintenance costs increased, the overall operational gains and cost savings indicate that automation provided a favorable balance between expenditure and performance.

Tarbit has examined the process of allocating a test's cost and found that a decrease in workload did not translate into a drop in laboratory expenses. Tarbit also looked into ways to recoup all costs, including capital expenditures and other overhead costs, via laboratory tests [7].

The impact of automation on test costs was observed in a study carried out in a teaching hospital laboratory [8]. A worksheet method is one of several approaches to cost analysis that have been used in studies conducted on small labs without access to automated tools [9].

For laboratory managers, controlling expenses through resource management is crucial since it allows them to make logical judgments regarding the daily operations of the labs [10]. Over the past few decades, there has been an increase in the amount of data pertaining to the cost analysis of the laboratory's clinical chemistry division. Authors have been examining the direct material costs rather than the total expenses [11, 12].

Authors doing prospective and retrospective research about the unit cost of tests in the clinical laboratory department enhanced these studies [13, 14]. Although writers have attempted to evaluate the CPT of semi-auto and completely auto chemistry analyzers and discovered a reduction in cost on the use of fully auto analyzers, the relative paucity of data on the CPRT of dry chemistry and wet chemistry analyzers still exists [15].

The quality of the reports produced is typically the main emphasis of all laboratories, but in the current automated era, the cost-effectiveness of the tools and procedures is one area that does not receive the attention it needs. As with any laboratory, the cost analysis of various chemistry analyzers is an overlooked aspect that requires further research; the expected CPRT for the equipment should also be taken into consideration when deciding whether to purchase a particular piece of equipment.

Generalizability

The study was conducted in a high-volume tertiary-care teaching hospital with established laboratory infrastructure. Therefore, the findings are likely generalizable to similar large government or teaching hospitals with comparable patient loads. Smaller laboratories or private diagnostic centers may experience different cost–benefit outcomes depending on their volume of tests, staffing patterns, and available resources.

Conclusion

The implementation of automation in the clinical chemistry laboratory at the institution led to significant improvements in efficiency, cost savings, and test output. Key benefits observed included a notable reduction in turnaround time, decreased labor costs, and minimized reagent wastage, all of which contribute to enhanced operational performance. Although annual maintenance expenses increased, the overall advantages of automation outweighed the additional costs.

Limitations

Since this study was conducted in a single urban tertiary care facility, it is not feasible to extrapolate the findings to the broader population. Additionally, the study's sample size was too small to draw conclusions and extrapolate findings.

Recommendations

As this was a short-term study, further research is needed with a longitudinal study design and a larger sample to achieve more definitive results.

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Conflict of Interest
The authors declare no conflict of interest related to this study.

Author Contributions
Manish Kumar Sinha: Conceptualization, methodology, data collection, manuscript drafting
Ratna Priya: Study design, supervision, data interpretation, manuscript revision
Chandan Kishore: Statistical analysis, data validation, tables, and results preparation
Madhu Sinha: Critical review, editing, and overall manuscript approval
All authors read and approved the final version of the manuscript.

Data Availability Statement
The data supporting the findings of this study are available from the corresponding author upon reasonable request. Patient confidentiality and institutional regulations will be strictly maintained.

List of Abbreviations
PMCH- Patna Medical College and Hospital
TTA- Task-targeted automation
TLA- Total laboratory automation
SD- Standard Deviation
CPRT- Cost Per Reportable Test

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