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Enhancing Customer Service and Quality in Municipal Water Testing Laboratories through Digital Transformation: A West Rand District Case, South Africa

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Abstract

This paper examines how digital transformation (DT) affects municipal water testing laboratories in the West Rand District, South Africa, a vital public health and environmental sector. The mixed-methods study examines how DT improves laboratory activities, customer service, and quality in resource-limited settings using qualitative observations and quantitative surveys, correlation analysis, ANOVA, and hypothesis testing. The findings show that DT significantly improves operational efficiency, customer satisfaction, and test accuracy. However, resource constraints, skill gaps, and change resistance prevent full adoption. The study offers solutions for overcoming these obstacles and implementing DT in municipal labs. These findings improve public-sector labs' understanding of DT and provide guidance for similar institutions worldwide. To reduce transformation resistance, future research should examine the wider impact of DT across public-sector departments and explore ways to improve employee engagement.

Keywords
Digital Transformation, Laboratory Information Management Systems, Customer Service, Quality Improvement.

1. Introduction
At a time when consumers expect prompt, precise, and dependable services, municipal water testing laboratories (referred to in this paper as municipal labs) are under growing pressure to enhance their turnaround times and service quality, with impatient customers as noted by Sunstein (2023) and Seol et al. (2024). Therefore, they anticipate rapid, trustworthy, and high-quality outcomes (Singh and Kumar 2023). The turnaround time and the accuracy, precision, and dependability of reports are measures of the quality of services (Dev Bhatt et al. 2019). In this context, municipal labs must identify ways to enhance their service performance to meet rising customer expectations.

Turnaround time is a crucial indicator of laboratory efficiency, commonly used by clinicians to assess the quality of laboratory services and often serves as a key performance metric (Alain et al. 2021a). Improving laboratory services requires a holistic approach that incorporates digital transformation (DT) strategies alongside traditional quality improvement tools such as Lean Six Sigma. DT offers laboratories the opportunity to optimize their operations, automate routine tasks, and reduce non-value-added activities, all of which contribute to faster and more reliable service delivery, as highlighted by Alain et al. (2021b) and Shiferaw and Yismaw (2019).

1.1 Problem Statement
Digital transformation or DT in laboratories refers to the integration of advanced digital technologies that optimize workflows, streamline processes, and enable real-time decision-making. By employing tools such as Laboratory Information Management Systems (LIMS), cloud-based data management, and automation technologies, laboratories can significantly improve their operational efficiency. Furthermore, advanced technologies like artificial intelligence

(AI) and the Internet of Things (IoT) provide real-time tracking, predictive maintenance, and automated data handling, all of which enhance the accuracy and speed of laboratory services (Zeier 2024; Comega 2022; Daniel et al. 2023). In municipal laboratories, where inefficiencies often arise due to outdated technology and bureaucratic processes, the application of these DT tools can lead to substantial improvements in service quality.

Middleware installation, systems automation, and the use of auto-verification systems also play a critical role in enhancing service delivery. Additionally, the implementation of barcodes, centralized equipment, and further staff training are proven methods to improve customer service (Ebubekir et al. 2017; Rajput and Jain 2018; Goldberg 2020). However, according to Shiferaw and Yismaw (2019), in government entities, delays and failures in turnaround times often result from a combination of factors such as equipment shortages, supply chain inefficiencies, environmental constraints, and cumbersome policies and procedures. In the South African municipal laboratory context, procurement delays are particularly problematic, often exacerbated by the multiple levels of authorization required by the Local Government: Municipal Finance Management Act 2003 (Republic of South Africa 2004).

Service delivery challenges in South Africa's government departments have long been an issue, with municipal and government laboratories perceived as underperforming (Chili et al. 2023; Shongwe and Meyer 2023; Morisset 2023). Both internal and external customers express dissatisfaction with turnaround times for tests, leading to a loss of business as customers switch to private service providers. Municipal labs have lost over 40% of external clients, while internal clients continue to report dissatisfaction. Additionally, Balfour et al. (2011) noted that the Department of Water Affairs (DWA) and other municipalities have begun outsourcing water sample testing to private laboratories due to the municipal labs' lack of capacity and capability Furthermore, Hawkins (2007), highlighted that the consequences of these service delivery issues include reduced revenue, lower customer satisfaction, and a tarnished reputation for municipal laboratories. Therefore, to address these challenges, the implementation of a comprehensive DT strategy is proposed. This strategy focuses on improving the operational efficiency of municipal labs by utilizing LIMS, remote work policies, and other technologies designed to enhance service delivery (Hawkins 2007).

1.2 Research Aim, Objectives, and Questions

This study aims to determine the impact of DT on customer service (CS), laboratory activities and processes (LAP), and overall laboratory quality within the municipal labs located in in the West Rand District, namely, Mogale City Local Municipality, Merafong, and Rand West in the Gauteng Province, South Africa. It further seeks to establish the current status quo of customer service and total quality within these laboratories.

The main research question of this study is: How the municipal laboratory customer services and service delivery can be improved through digital transformation (DT)? From this main research question, the following sub-research questions or SRQs are formulated: (SRQ1) What are the key municipal labs activities and processes that play a critical role in enhancing customer satisfaction? (SRQ2) To what degree do municipal labs services impact overall customer satisfaction with the services provided? (SRQ3) What are the perceptions of the laboratory personnel regarding the organization's journey of digital transformation (DT)? (SRQ4) To what extent does digital transformation (DT) contribute to the enhancement of laboratory activities and processes (LAP) within the municipal context? (SRQ5) What is the digital transformation (DT) status quo within the municipal labs' context?

1.3 Research Scope and Limitations

The study is only limited to the municipalities in West Rand District, namely, Mogale City Local Municipality, Merafong, and Rand West in the Gauteng Province of South Africa as shown in Figure 1. The study methodology involved observation and survey, which is a checklist and questionnaires.

Questionnaires were arranged into segments and given to the respondents within the municipalities, while an observation checklist was constructed to determine the municipalities' digital transformation status quo. The study may somehow not prove to be generalizable to municipalities nationwide and globally.

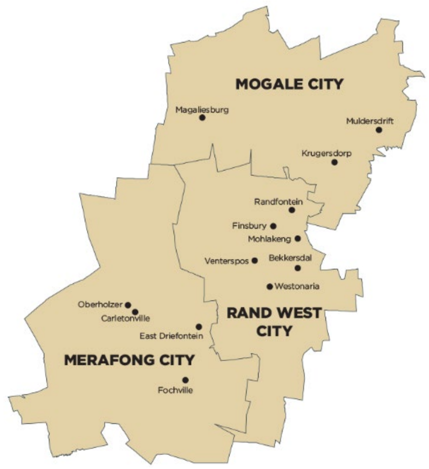

Figure 1. West Rand District (Source: Muslim Supreme Council of South Africa, 2019)

2. Literature Review

2.1 An Overview of Digital Transformation (DT) in Public Sector Services

The late 1990s and mid-2000s saw the rise of DT as computerized and automated processes streamlined operations (Heilig et al. 2017). Additionally, Heilig et al. (2017) posit that DT is divided into paperless, automated, and smart systems, with these phases corresponding to 1980s, 1990s-2000s, and 2010s technological advances.

DT simplifies internal processes to boost productivity, lower costs, and improve customer service (Gertzen et al. 2022; Mutwa 2021), reduces inefficiencies, improves policies centered on customers (Mutwa 2021) and improves service quality in municipal laboratories (Latupeirissa et al. 2024). These labs can improve operational performance and customer satisfaction by using digital tools and automating repetitive tasks to get more accurate results faster.

2.2 Digital Transformation (DT) and Laboratory Information Management Systems (LIMS)

Laboratory Information Management Systems (LIMS) play a central role in the DT of laboratories by offering a unified platform to manage sample data, experimental workflows, and equipment use. According to Latupeirissa et al. (2024), LIMS increases operational efficiency by automating routine processes like sample tracking, data entry, and results dissemination, which minimizes human error and standardizes workflows across the lab.

Moreover, LIMS supports quality control and compliance by ensuring adherence to standard operating procedures (SOPs), which not only enhances the accuracy of lab results but also facilitates the audit trail needed for regulatory compliance as indicated by Latupeirissa et al. (2024). In public sector laboratories, where efficiency is crucial, LIMS helps standardize operations, centralize data, and automate workflows, thereby improving service delivery (Alenazi and Bugis 2022).

A case in point is the LIS360 system, which integrates with hospital information systems (HIS) to enable real-time data sharing between departments. This enhances turnaround times for test results and supports clinicians in making timely decisions. The system's advanced quality control features, including automated quality control charts and alarms when instruments fall out of specification, ensure the reliability of laboratory results (Latupeirissa et al. 2024).

2.3 Digital Transformation (DT) and Customer Services

Digital advancements change how companies interact with customers. Cloud-based systems improve efficiency and user experience, replacing traditional business models. Robotics, big data, AI, and the IoT are improving customer service in many industries, including laboratory services (Fu et al. 2023; Guzmán-Ortiz et al. 2023). These innovations help laboratories deliver faster and more accurate results, improving patient and clinician satisfaction.

In the context of LIMS, customer service benefits from real-time result tracking, which reduces waiting times and improves service transparency. Furthermore, LIMS systems offer customizable reporting and communication options tailored to the specific needs of different stakeholders (Third Wave Analytics 2024). This level of customization helps laboratories meet diverse expectations while improving the overall user experience.

2.4 Digital Transformation (DT) and Quality

DT enhances not only technology and processes but also influences strategy, culture, staff engagement, and innovation within organizations (Montero Guerra et al. 2023). It has the potential to shift the traditional quality culture from a focus on policing to one centered on continuous improvement. Furthermore, it has been suggested that digitalization contributes to better quality management by improving the quality of products and services in organizations (Elg et al. 2020).

In laboratories, LIMS plays a pivotal role in quality management by automating quality control tasks and ensuring compliance with international standards. For example, AI-enabled systems like LIS360 facilitate real-time monitoring and quality checks, ensuring the accuracy of lab tests. Automation in detecting and reporting errors further minimizes human involvement, accelerating decision-making and improving service quality Fu et al. 2023). Additionally, LIMS ensures that test results are easily accessible and verifiable, which expedites decision-making and promotes faster reporting. These capabilities are vital for maintaining high standards in laboratory services.

2.5 Laboratory Activities and Processes

According to Miao (2021), a process encompasses any activity or set of activities utilizing resources to transform inputs into outputs. In the context of laboratories, processes involve transforming samples into results through the use of laboratory resources. Laboratory processes are broadly categorized into three phases: pre-analytical, analytical, and post-analytical (Casler 2022). Each phase consists of specific activities, as outlined in Table 1.

Table 1. Laboratory Activities and Processes (Casler 2022)

Laboratory Process	Laboratory Activity
Pre-analytical phase	• Quotation generation and payment, • Sampling and transportation, • Sample reception, handling, preparation, • Instrument calibration
Analytical phase	• Sample analysis • Quality assurance of results
Post-analytical phase	• Test result approval • Report generation • Customer support • Communication

Laboratory processes in South African municipal laboratories are predominantly manual and adhere to traditional methodologies. This includes manual sampling, marking of bottles with permanent markers for identification and traceability, and the use of handwritten checklists for sample reception and recording. Samples are subsequently distributed to different laboratory sections based on customer requirements, where they undergo manual preparation for analysis.

The analytical phase relies on specific procedures, with results documented manually or printed from analytical instruments and then manually transcribed into reports. Report generation and approval are also conducted manually and typically require on-site presence. The reliance on manual processes is attributed to inadequate resources, insufficient infrastructure, limited skilled personnel, and time constraints (Badr 2018).

While manual processes are cost-effective and require minimal equipment, they are inherently prone to human error, leading to inefficiencies, prolonged turnaround times, compromised result quality, and challenges in traceability (Islam 2023). In contrast, automated systems offer significant long-term benefits, including enhanced standardization, reduced operational congestion, and improved sample management. Automation supports accreditation and certification processes, ensures higher testing quality, and reduces the volume of samples required. Furthermore, it minimizes biological risks for operators, facilitates staff requalification, and enhances job satisfaction. These advantages underscore the potential of automation to transform laboratory operations and address the inefficiencies of traditional methods.

2.6 Lab 4.0

The rise of Industry 4.0 (IR 4.0) has paved the way for Lab 4.0, a transformative model that leverages automation, robotics, and interconnected technologies to enhance laboratory efficiency, regulatory compliance, and scientific research (Bayode et al. 2019). Unlike traditional automation, Lab 4.0 fosters seamless communication between instruments via computerized systems, enabling real-time data exchange and adaptive workflows (Gauglitz 2018; Miao 2021). Innovations such as AI-driven robotic arms and automated liquid-handling systems illustrate this evolution, minimizing human intervention, cutting operational costs, and significantly increasing throughput (Paskanik 2020).

Beyond improving operational efficiency, Lab 4.0 introduces standardized workflows that enhance accreditation readiness while mitigating biological risks. It also optimizes test accuracy and sample management, allowing laboratory personnel to focus on more complex analytical tasks (Lippi and Da Rin 2019). These advancements align with the broader shift toward smart laboratories, where physical and digital processes integrate to enhance flexibility and service delivery (Gimpel et al. 2018).

Scholarly perspectives further refine the concept of Lab 4.0. Ktori (2020) identifies cloud computing and IoT as foundational elements of the "smart laboratory," enabling decentralized decision-making and scalable compliance. In clinical applications, Lippi and Da Rin (2019) highlight the role of autonomous diagnostics and safety protocols in reducing human error. Additionally, Gauglitz et al. (2018) introduce cyber-physical systems (CPS), which create a dynamic bridge between laboratory instruments and digital platforms, facilitating predictive maintenance and process adaptability. Taken together, these insights define Lab 4.0 as the integration of Industry 4.0 technologies—IoT, AI, and CPS—into cohesive digital ecosystems that optimize resource allocation, enable real-time analytics, and transform laboratories into highly efficient, data-driven environments.

For successful implementation, alignment with organizational objectives is essential. This involves conducting process reviews to identify optimization opportunities, such as eliminating manual data entry, and establishing robust data-management systems to ensure transparency and enable paperless operations (Ktori 2020; Spencer 2021). Furthermore, close collaboration between informatics and operational processes is crucial for maintaining traceability and adherence to industry standards (Bietenbeck and Ganslandt 2018). Ultimately, Lab 4.0 redefines laboratory operations by enhancing efficiency, fostering interdisciplinary collaboration, and balancing human expertise with technological innovation.

3. Methods

3.1 Research Design

As stated by Trott (2021), the evolution of DT has led to "Lab 4.0," where automation and robotics improve lab workflows. Furthermore, Trott (2021) adds that automation helps this generation of labs perform routine tasks more accurately and efficiently. This transformation relies on LIMS systems like LIS360 to automate data collection, quality control, and sample tracking. Reduced manual interventions reduce errors, streamline operations, and speed up processes, improving service quality and operational performance (Third Wave Analytics 2024; Fu et al. 2023).

This study employs a mixed-methods approach, integrating both qualitative and quantitative research methodologies to investigate the impact of DT on municipal laboratory services. It is important to indicate that Sharma et al. (2023) notes that utilizing this design, the research can provide a more holistic view of the issue, drawing from multiple data sources to deepen the analysis and enhance the overall validity of the findings.

The quantitative aspect follows a correlational research design, aiming to identify and measure the relationships between key variables: Digital Transformation (DT) as the independent variable, and Laboratory Activities and Processes (LAP), Customer Service (CS), and Quality Improvements (QI) and Personnel Perception (PP) within municipal laboratories, as dependent variables (See Figure 2 depicting the conceptual framework). According to Saraswati and Devi (2023), this combination of methods allows for a nuanced exploration of both statistical trends and contextual insights.

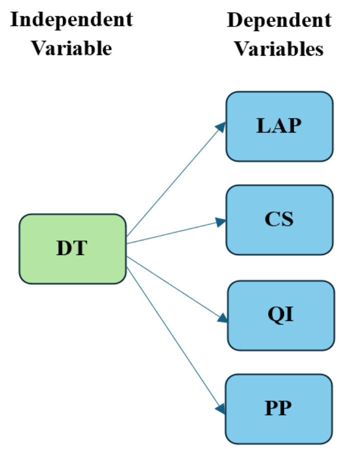

Figure 2. Study's Conceptual Framework

3.2 Research Hypotheses

This study uses Digital Transformation (DT) as the independent variable and Laboratory Activities and Processes (LAP), Customer Services (CS), Quality Improvement (QI), and Personnel Perceptions (PP), as the dependent variables as shown in Figure 2 above. Research hypotheses for this study are:

- H_1: DT of the municipal laboratory will improve processes such as generating quotations, receiving samples, conducting analyses, ensuring quality, approving results, releasing reports, and improving communication (LAP).
- H_{01}: DT in municipal laboratories does not improve processes such as generating quotations, receiving samples, conducting analyses, ensuring quality, approving results, releasing reports, and improving communication (LAP).
- H_2: DT in laboratories leads to significant improvements in CS and QI compared to non-digital transformation.
- H_{02}: DT does not significantly improve CS and QI in municipal laboratories.
- H_3: Positive PP positively impacts DT implementation within the organization.
- H_{03}: PP of DT do not favor its implementation within the organization.

The independent-dependent variable relationship informs these hypotheses, which are derived from research questions. Hypotheses were tested using a one-tailed t-test and p-value with a 5% significance level.

3.3 Sample and Population

The target population for this study includes both technical and managerial staff from municipal water laboratories in the West Rand District, specifically those located in Mogale City, Merafong, and Rand West. A probability sampling technique was applied, ensuring that all individuals within the population had an equal likelihood of being selected, as noted by Rahman et al. (2022). The sample size was determined based on the guideline of having a minimum of five cases per questionnaire item, leading to a required sample size of 200 participants. To verify the adequacy of the sample, the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's test of sphericity were conducted, ensuring that the data were appropriate for further statistical evaluation (See Table 2 below).

Table 2. Kaiser-Meyer-Olkin (KMO) & Bartlett's Test Results

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.879
Bartlett's Test of Sphericity	Approx. Chi-Square	2 532.197
	Df	435
	Sig.	< 0.001

From Table 1, the KMO measure of sample adequacy is 0.879, which is more than 0.5. Hence, the sample size for the study is deemed sufficient.

3.4 Data Collection Instruments

The study followed a mixed methods approach, as mentioned earlier, and as such, the data collection instruments relating to each methodology are described in these sub-sections.

- Quantitative Data Collection: Structured questionnaires were utilized to collect quantitative data, distributed both electronically through Google Forms and in hard copy formats. The questionnaire was organized into six sections: (A) demographic information, (B) laboratory activities and procedures, (C) customer service, (D) quality improvement, (E) personnel perceptions of digital transformation, and (F) the overall impact of digital transformation on laboratory processes. Participants were asked to provide their responses using a 5-point Likert scale, ranging from "strongly disagree" to "strongly agree," allowing for the measurement of attitudes and perceptions across various dimensions related to the study's questions. Below is a detailed description of the questionnaire coded questions:
    - Section B – Laboratory Activities and Processes (LAP): LAP1 for Sample analysis quotation, LAP2 for Sample receiving, LAP3 for Sample handling, LAP4 for Sample analyses, LAP5 for Assuring results quality, LAP6 for Test results approval, LAP7 for Test report release, and LAP8 for Communication.
    - Section C – Customer Services (CS): CS1 for customer invoicing and payments, CS2 for results turn-around time, CS3 for lab report quality, CS4 for customer satisfaction, CS5 for lab-customer communication, and CS6 for technical advice and guidance.
    - Section D – Quality Improvement (QI): QI1 is General laboratory Practice, QI2 is Sample handling, QI3 is Personnel competency, QI4 is Customer service, QI5 is Test results and reports, and QI6 is Customer feedback and satisfaction.
    - Section E – Personnel Perception (PP) of DT: PP1 for lack of skills, PP2 for lack of resources, PP3 for lack of political support, PP4 for lack of managerial support, PP5 for organizational complexity, PP6 for resistance to change, PP7 for bureaucratic culture, and PP8 for fear of innovation and job loss.
    - Section F – Digital Transformation (DT): DT1 for laboratory activities and processes, DT2 for customer service and service delivery, DT3 for total quality improvement, DT4 for reduced operational cost and human error, DT5 for reduced turn-around time and just-in-time improvement, DT6 for job scheduling and continuous process feedback, and DT7 for resource and data management.
- Qualitative Data Collection: An observation checklist was employed to evaluate the current state of digital transformation within the laboratories. This checklist focused on key elements such as the organization's strategic vision for digital advancement, the existing culture of innovation, the level of digital capabilities among staff, and the availability and use of technological assets. By systematically observing these aspects, the checklist provided a practical means of assessing how deeply digital transformation initiatives had been integrated into the laboratory operations and infrastructure.

3.5 Data Analysis

The collected data were analyzed using SPSS Version 28. Descriptive statistics, such as mean scores and standard deviations, were used to summarize the quantitative data. Pearson's correlation coefficient was applied to explore the relationships between DT and key variables, including LAP, CS, and QI. Additionally, Exploratory Factor Analysis (EFA) was conducted to evaluate the construction validity of the questionnaire items and to uncover underlying relationships within the data. This approach allowed for a deeper understanding of the factors influencing digital transformation in municipal laboratories.

3.6 Validity and Reliability

Cronbach's Alpha was used to evaluate research instrument reliability, with 0.70 or higher being acceptable (Taber 2018). This ensured consistent measurement of the intended constructs. Table 3 indicates the internal reliability of the constructs in the study. The constructs' reliability was assessed by SPSS Version 28, and the Cronbach Alpha values were obtained. All the constructs have Cronbach of higher than 0.7. Meaning that there is consistency and reliability within the constructs and questionnaires.

Table 3. Internal Reliability Table

Constructs	Cronbach α coefficient	Number of Items
LAP	0.922	8
CS & QI	0.951	12
PP	0.886	8
DT	0.879	7

The instruments' face and content validity were checked to ensure they captured the key concepts under investigation. These steps verified the study's tools' reliability and validity.

3.7 Ethical Considerations

Ethical approval for the study was secured from the Ethics Committee of the Faculty of Engineering and the Built Environment at the University of Johannesburg. Participants were fully informed about the purpose and objectives of the study and provided with an informed consent form before participating. Measures were taken to ensure the confidentiality and anonymity of all participant data, and these ethical standards were upheld throughout the entire research process to protect the rights and privacy of the individuals involved.

4. Results and Discussion

The Results and Discussion section summarizes the key findings on DT's impact on LAP, CS, and QI, then analyzes major barriers to digital transformation, potential improvements, and the implications of these findings in relation to existing literature, while starting with the description of the respondents.

A total of 121 responses were obtained, yielding a response rate of 40.33%. However, 6 out of 121 responses were not fully completed. Therefore, only 115 responses received from the municipalities within the West Rand District, including Mogale City, Merafong, and Rand West City were deemed valid.

The survey categorized respondents into four skill levels: Professional, Skilled, Semi-skilled, and Unskilled. As shown in Figure 3 below, among these, the Skilled group represents the largest share, followed closely by Professionals. Semi-skilled individuals make up a moderate portion, while the Unskilled category is the smallest. This distribution highlights a workforce with a strong presence of higher-skilled individuals, suggesting an emphasis on specialized or technical expertise in the surveyed population.

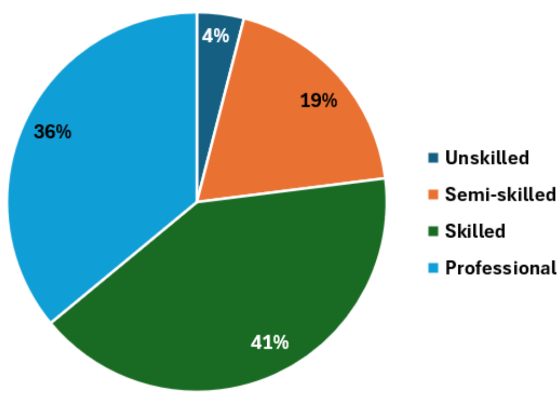

Figure 3. Respondent Skills Distribution

Quantitative and qualitative data were analyzed to reveal the following key insights:

4.1 Key Findings on DT in Municipal Water Laboratories

Laboratory Activities and Processes (LAP): Over 75% of respondents expressed satisfaction with lab processes like sample handling, analysis, and reporting, with mean satisfaction scores ranging from 3.93 to 4.19 (on a 5-point scale). However, communication and quality assurance saw higher dissatisfaction rates, with up to 6.9% of participants unsatisfied, indicating that while efficiency has improved, communication remains a challenge. Customer Service (CS): More than 70% of participants rated customer service as very good to excellent, especially in customer satisfaction (mean score 4.17) and communication (mean score 4.04). However, 7.9% were dissatisfied with invoicing, payments, and turnaround time, suggesting that service logistics and speed still need improvement.

- *Quality Improvement (QI):* Over 80% of respondents rated quality improvement efforts highly, particularly in personnel competency (mean score 4.25) and test result quality (mean score 4.09), indicating a strong positive impact of DT on maintaining high standards in laboratory operations.

- *Personnel Perception (PP) towards DT:* Respondents had mixed views on DT. While 46.1% said a lack of skills hampered the process, 30.4% disagreed. Similarly, 55.7% thought resource shortages were a barrier, while 25.2% disagreed. These findings suggest that while DT is generally supported, concerns remain about the skills and resources needed to implement it.
- *DT in Municipal Water Laboratories:* The findings demonstrate strong support for DT in municipal laboratories:
    - *Effectiveness of DT:* Over 80% of respondents agreed that DT enhances laboratory activities, CS, and service delivery, with a mean score of 4.25, indicating a widespread belief in its positive impact on operations.
    - *Cost and Error Reduction:* 72.2% agreed that DT reduces operational costs and human error (mean score 3.97), suggesting that automation is viewed as a key factor in driving efficiency.
    - *Turnaround Time and Job Scheduling:* 79.1% acknowledged improvements in turnaround times, and 82.6% noted better job scheduling and process feedback (mean score 4.14), highlighting the value of digital tools in streamlining workflows.
    - *Resource and Data Management:* The highest support (87.8%, mean score 4.32) was for the role of DT in improving resource and data management, reflecting strong confidence in its ability to manage laboratory data effectively.
    - *Minor Skepticism*: A small minority (2.6%-7.9%) expressed doubts, particularly regarding cost reduction and QI, indicating that some skepticism or resistance remains.

4.2 Barriers to DT

The study identified several key barriers to the full implementation of DT:

- *Shortage of Resources:* Over 55% of participants agreed that resource limitations, including inadequate funding, outdated infrastructure, and insufficient technological assets, restricted the adoption of digital technologies in the laboratories.
- *Skills Gaps:* Nearly 46% of respondents pointed to a lack of technical expertise and the inability to adapt to new digital workflows as significant challenges to DT.
- *Resistance to Change:* More than 53% of respondents cited organizational resistance, including fears of job loss and reluctance to adopt new technologies, as obstacles to the transformation process.
- *Lack of Strategic Vision:* Observation findings revealed that none of the municipalities had a clear strategic plan for DT, with leadership unaware of how digital tools could align with broader business goals.

4.3 Statistical Analysis and Hypothesis Testing Results

The results of the correlation analysis, ANOVA, beta coefficients, and hypothesis testing offer critical insights into the impact of DT on municipal labs operations:

- *Correlation Analysis:* A moderately positive correlation was found between DT and LAP ($r = 0.407$, $p < 0.001$), indicating that digital tools enhance operational efficiency in areas like sample handling and reporting. The strongest correlation was with CS and QI ($r = 0.510$, $p < 0.001$), demonstrating that digitalization greatly improves customer service and lab output quality. A weaker correlation was observed with PP ($r = 0.203$, $p = 0.030$), suggesting that while DT improves operations, its influence on employee attitudes is more limited.
- *ANOVA:* ANOVA results confirmed the significant impact of DT on LAP ($F = 22.384$, $p < 0.001$), CS & QI ($F = 39.785$, $p < 0.001$), and PP ($F = 4.835$, $p = 0.030$). This reinforces the positive effects on operations and customer satisfaction but also highlights that its impact on personnel is less strong.
- *Beta Coefficients and Hypothesis Testing:* Below are the Beta Coefficient as well Hypothesis Testing results. These results are also shown in Table 4 below:
    - **H_1 (LAP):** The beta coefficient for LAP ($\beta = 0.442$, $p < 0.001$) confirms that DT significantly enhances LAP.
    - **H_2 (CS & QI):** The beta for CS & QI ($\beta = 0.568$, $p < 0.001$) supports the hypothesis that DT greatly improves CS and QI, as shown in Table 3.
    - **H_3 (PP):** The beta for PP ($\beta = 0.284$, $p = 0.030$) supports the hypothesis that DT influences PP, though the effect is weaker, suggesting the need for more efforts to change employee attitudes.

Table 4. Hypothesis Results of the Study

	Regression weights	β	t	p	R^2	Results
H_1	DT → LAP	0.442	4.731	<0.001	0.407	Supported
H_2	DT → CS QI	0.568	6.308	<0.001	0.510	Supported
H_3	DT → PP	0.284	2.199	0.030	0.203	Supported

4.4 Findings from Observations

Qualitative data from direct observation examined digital transformation in one of the three West Rand District municipal laboratories in the six dimensions detailed below:

- *Strategic Vision:* A clear strategic vision or plan for DT was lacking in the laboratory. Lack of leadership understanding of DT and their alignment with business goals prevented a focused digital roadmap.
- *Culture of Innovation:* The absence of a culture of innovation and resistance to change hindered the adoption of digital practices. Cultural barriers to change prevented the organization from rewarding innovators.
- *Intellectual Property:* The lab used outdated software and a few modern digital tools. Budget constraints delayed investment in new digital solutions and intellectual property, stalling operational performance improvements.
- *Digital Capabilities Status:* Although technical expertise was present, there was no formal assessment of digital skills. Despite talent, digital capabilities were lacking, preventing full digital strategy execution.
- *Strategic Alignment:* Lack of budget and resources for DT, and limited collaboration between digital and business units. Small digital initiatives like cloud services adoption showed weak strategic alignment.
- *Availability of Technology Assets:* While some technology infrastructure, like cloud computing and internet tools, was in place, underfunded technologies like data analytics hindered digital transformation.

5. Conclusion and Recommendations

5.1 Conclusion

Qualitative data from This study examined how DT affects municipal water laboratory's LAP, CS, PP and QI. DT maximizes laboratory efficiency, lowers operational costs, and improves customer satisfaction. Sample handling, result reporting, and job scheduling automation have reduced human errors, turnaround times, and feedback processes.

The study's key findings show that 77% of respondents liked more efficient sample analysis and reporting. The correlation (r = 0.407) shows that DT improves operational efficiency. With regards to CS and QI 74.5% rated CS "very good" or "excellent," and 79.4% liked QI. DT improved communication, accuracy, and responsiveness and correlated more with CS/QI (r = 0.510). Looking at PP, it was found that despite operational improvements, 49.46% resist DT due to lack of digital skills, job security concerns, and change resistance.

5.2 Recommendations

Based on the findings and conclusions drawn earlier, the study is suggesting the following recommendations for consideration:

- Install and maintain Laboratory Information Management Systems (LIMS) to streamline data management, sample tracking, and reporting, improving efficiency and reducing errors.
- Implement IoT Sensors and Big Data Analytics: Monitor equipment with IoT sensors to reduce downtime and gain insights and improve decision-making.
- Employee Training and Change Management: Continue digital tool training and implement change management programs to reduce resistance, improve adaptability, and align staff perceptions with technology.
- Create a Strategic Vision: Align laboratory staff, management, and customers' goals with a clear, measurable digital transformation roadmap.
- Support Technology and Innovation: Fund intellectual property, technology upgrades, and infrastructure to support digital transformation.

5.3 Suggestions for Future Research

This study focused on municipal laboratories in the West Rand District and may not be generalizable to other sectors or regions. Future research should examine the broader impact of digital transformation across various municipal departments and employ mixed-method approaches to capture deeper insights into its influence on service delivery and organizational culture.

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