Assessing the cost and utilization of SMS printers by primary health care facilities: lessons learned from South Africa

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Abstract

Background. Historically, paper-based laboratory reports were delivered by couriers to health facilities resulting in post-analytical delays. As a result, short message service (SMS) printers were deployed to fill this gap, with the global data service platform (GDSP) being primarily used to facilitate deployment. In addition, these printers generate binary and quantitative information that can be used to assess utilization.

Objective. The objective of this study was to determine the costs and utilization of the SMS printer program in South Africa.

Methods. A cost analysis for 2020 was undertaken. We determined annual equivalent costs (AEC) for staffing, printers, fixed costs related to the national coordinator, consumables, travel costs, database support/hosting/dashboard development, printer repairs, and results transmission. The main outcome of interest was the cost per SMS printer result delivered. Data were extracted to assess utilization as follows: i) months active (based on internet protocol data); ii) signal; iii) battery strength.

Results. There were 4,450,116 results delivered to printers that were situated at 2232 primary health care facilities. An AEC of $687,727 was reported, with a cost per result delivered of $0.1618. The SMS printers contributed 73.52% to the total AEC. Overall, 90% of the printers were GDSP based, of which only 69.5% were determined to be active. The majority of active printers reported a signal strength of ≥60% and a battery strength of ≥6 volts.

Conclusion. Although the SMS printer program has the potential to reduce post-analytical delays, pathology services should migrate to an end-to-end electronic interface to improve patient care.

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Key words: SMS printer; costing; post-analytical; laboratory result; utilization.

Contributions: WSS, LSI, MPS, supervision of the study, and revising the manuscript critically; NC, developing the methodology, conducting the costing analysis, and preparing the first draft of the manuscript; FO, providing the costing and test volume data; NC, FO, LSI, substantial contributions to the conception of this study. All authors approved the final version to be published.

Conflict of interest: the authors declare no potential conflict of interest.

Ethics approval and consent to participate: ethical clearance was obtained from the University of the Witwatersrand Human Research Ethics Committee (HREC) Medical (M160978).

Informed consent: this study did not use any patient identifiers and patient consent was not required.

Availability of data and material: the authors do not have permission to share the costing data.

Acknowledgments: the authors would like to thank TLC engineering solutions, and the NHLS for their support of the SMS program. They would also like to thank Shaun Grimett, the laboratory information system (LIS) manager, for extracting the TrakCare WebView data.

Received for publication: 24 June 2022.
Accepted for publication: 3 August 2022.
Early view: 19 April 2023.

Journal of Public Health in Africa 2023; 14:2253
doi:10.4081/jphia.2023.2253

Introduction

The National Health Laboratory Service (NHLS) operates a platform of 268 laboratories across South Africa, with a mandate to provide cost-effective and efficient diagnostic services to the public healthcare sector.[1] The NHLS performs the majority of HIV and tuberculosis (TB) testing for over 80% of the population in South Africa.[1]

Historically, the clinic-laboratory interface was entirely paper-based. In the pre-analytical phase, the health care worker (HCW) completes the laboratory request form to order tests for a patient. Similarly, in the post-analytical phase, the laboratory reports are printed, sorted by courier route, and then packaged and hand-delivered by the national courier network to each primary health care (PHC) facility. This was a time-consuming process and we estimated that it resulted in a delay of between one to two days from laboratory report printing to use by the health facility. This was supported by reported complaints at the HIV and TB national and provincial meetings prompting the deployment of the short message service (SMS) printers. To address this gap, in 2009, the NHLS partnered with TLC Engineering Solutions (Johannesburg, South Africa) to develop a global system for mobile communications (GSM)-based SMS printer that would deliver laboratory results to the health facility shortly after validation on the laboratory information system (LIS).[2] This dramatically reduced the time from result generation to delivery at the health facility. Subsequently, these SMS printers have been deployed by various funding agencies across Africa.[3]

One of the challenges with the original SMS printers was the one-way communication of results, *i.e*., from the LIS to the printer. Therefore, in 2013, a bi-directional printer was developed to make it possible for the HCW to use a barcode scanner to read the laboratory request form tracking barcode and retrieve the desired results within a few minutes by communicating with the LIS.[4] This made it possible to act on laboratory results while the patient was still at the health facility, potentially reducing loss to follow-up (LTFU).

SMS printers are placed at 2232 PHC facilities offering antiretroviral therapy (ART) across 52 districts in South Africa. The rationale for this deployment was to facilitate the rapid delivery of results for same-day ART initiation.[5] Originally, the SMS printers reported a limited test repertoire that has been increased to include TB (Xpert® MTB/RIF Ultra), core HIV testing [cluster of differentiation 4 (CD4), HIV viral load, HIV DNA polymerase chain reaction (PCR)], ART monitoring (creatinine clearance and hepatitis B surface antigen) and advanced HIV disease screening (reflex cryptococcal lateral flow assay).

Recently, the majority of SMS printers were transitioned from GSM to the global data service platform (GDSP). One of the benefits of the switch to GDSP is the use of destination internet protocol (IP) address communication that is more secure and efficient than conventional GSM. These GDSP SMS printers generate an automated heartbeat message that regularly transmits the following binary and quantitative information: printer status; printer cover open; paper out; printer head error; connectivity signal percentage; barcode scanner connected; battery voltage; the number of results pushed (from LIS to printer) and pulled (via barcode scanning); last result date and last heartbeat date.[4] This data is sent to a national server that allows for the remote monitoring of the performance and utilization of the SMS printers. Interactive dashboards have been developed to monitor this platform.

Objective

The objective of this study was to determine the costs of the SMS printer program in South Africa. A secondary objective was to assess the utilization of these devices by analyzing the remote monitoring data. In addition, the coverage of the SMS printer delivered results was assessed against national test volumes.

Materials and Methods

Ethical considerations

Ethical clearance was obtained from the University of the Witwatersrand Human Research Ethics Committee (HREC) Medical (M160978). Our study did not use any patient identifiers and patient consent was not required.

Cost analysis

The top-down cost analysis was undertaken using Microsoft Excel (Redmond, WA, USA) and Stata 17 SE (College Station, TX, USA). The annual equivalent cost (AEC) was determined for each cost category and used to determine the cost per SMS printer result delivered. The costs are based on the end-to-end delivery of the SMS program.

We obtained AEC using expenditure data from NHLS and manufacturer-supplied quotations for the 2020 calendar year. The number of SMS results delivered was extracted from the remote monitoring dashboard. A provider perspective is taken; all costs are reported for the NHLS as the provider of the SMS program. The main outcome of interest was the cost per SMS printer result delivered. All costs were collected in South African Rands (ZAR) and reported in United States Dollars (USD) using an exchange rate of 14.69 (International Monetary Fund period average exchange rate for 2020).[6] The Consolidated Health Economic Evaluation Reporting Standards checklist was used in the preparation of the manuscript.[7]

We determined AEC for the following categories: i) staffing; ii) procurement of SMS printers; iii) fixed costs related to the national SMS coordinator; iv) SMS consumables provided; v) SMS coordinator travel costs; vi) database support, hosting, dashboard development; vii) SMS printer repairs; viii) SMS results transmission. We assumed a working life of 3 years (the standard period for NHLS tenders) and a discount rate of 4%. This is based on the inflation, consumer prices (annual %) value of 4.124 and 3.224% reported by the World Bank for 2019 and 2020 respectively.[8] We excluded overhead costs for this analysis. The organizational cost of overheads was excluded and includes all corporate services offered such as human resources, finance, information technology, *etc*. These services are offered by the corporate offices of the NHLS.

For staffing, we used the percentage of full-time equivalent dedicated to the SMS program for the national coordinator, based on the NHLS mid-point cost to company salary scales. We used quotations from TLC Engineering Solutions for the SMS printers and multiplied this by the number installed at health facilities. We included the costs of a laptop, office desk, office chair, computer monitor, keyboard, wireless mouse, projector (used for training), and laptop bag provided to the SMS coordinator. For the SMS printer consumables, we reported the AEC for printer paper rolls provided by NHLS laboratories to health facilities (using historical expenditure data). Health facilities use the order book for specimen collection materials to order SMS printer paper refills.[9] We determined the travel AEC for the SMS coordinator based on expenditure data for accommodation, flights, car hire, and subsistence claims. For the database support, hosting, dashboard development, and SMS printer repairs provided by TLC engineering solutions, we determined the AEC from the historical expenditure data. This also included the costs related to the dashboard development, server hosting, database support, SMS printer connectivity, sim card charges, global data sim platform, printer repairs provided, and the provision of printer repair toolkits (for in-field repairs). For SMS results transmission AEC, we multiplied the number of results transmitted by the unit cost provided by the supplier.

Statistical analysis

We analyzed the number of test results delivered to SMS printers in the study period. We compared these values to national test volumes to assess the national coverage of SMS printers. We assessed what percentage of national test volumes originated from PHC facilities and determined the coverage per test. Aggregate test volumes by facility type were extracted from the Corporate Data Warehouse for HIV viral load, CD4, HIV DNA PCR and Xpert® MTB/RIF Ultra testing to determine the proportion to assign as originating from PHC facilities. It was assumed that 40% of the remaining SMS repertoire tests were from PHC facilities. The SMS coverage per test was recalculated using the adjusted PHC test volumes. We reported the AEC per cost category, as well as the cost per SMS printer result delivered (USD). We used a flow chart to report what proportion of the 2232 printers were GDSP and non-GDSP. The data extracted from the GDSP printers were used to assess utilization. We reported what proportion were classified as active, determined by communication to the allocated IP address for one or more months across the study period. The maximum signal (0 to 100%) was assessed across the study period and reported what proportion of printers had values ≥60%. Similarly, we assessed what proportion of printers reported a maximum battery strength of ≥6 volts. We determined the first and last transmission for all active printers to determine for how many months they were active. We reported the median value per province.

Results

In 2020, there were 4,450,116 results delivered to SMS printers that were situated at 2232 PHC facilities.

Results delivered to SMS printers

The majority of the results delivered to SMS printers in South Africa were for HIV viral load (51.1%: n=2,275,930), CD4 (20.9%: n=929 032), Xpert® MTB/RIF Ultra (12.8%: n=570,176) and creatinine (5.4%: n=239,750) (Table 1). These four tests accounted for 90.2% of SMS results delivered (n=4,014,888). Early infant diagnosis (HIV DNA PCR) accounted for 4.6% of results delivered (n=205,997).

SMS printer results coverage

Overall, for HIV viral load, CD4, HIV DNA PCR and Xpert® MTB/RIF Ultra testing, the results delivered by SMS printers contributed to national coverage percentages of 39, 40, 30.6 and 36.% respectively (Table 1). The creatinine, reflexed cryptococcal antigen, and hepatitis B surface antigen reported coverage percentages of 2.1, 23.5 and 10% respectively.

Aggregated data revealed that 85.2, 77.2, 85.2 and 81.4% of HIV viral load, CD4, HIV DNA PCR and Xpert® MTB/RIF Ultra testing were requested by PHC facilities. For the other tests, an overall proportion of 40.0% was used (data not shown). After the adjustment, the HIV viral load, CD4, HIV DNA PCR and Xpert® MTB/RIF Ultra coverage increased to 45.8, 51.8, 49.6 and 44.2% respectively. The coverage for the other tests ranged from 5.2 to 58.8%.

Cost to deliver and end-to-end SMS printer program

An AEC cost of $687,727 was reported for the SMS printer program (Table 2). The SMS printer devices contributed 73.52% of the total AEC. This was followed by database support/hosting/dashboard development, staffing, and results transmission which contributed 7.43, 6.80 and 6.61% respectively. The cost per SMS printer result delivered was $0.1618.

SMS printer utilization

Overall, 90% (n=2,010) of the printers were based on the GDSP platform (Figure 1). Of these GDSP printers, only 1397 (69.5%) were determined to be active based on IP communication. A signal strength ≥60% was reported for 1219 (87.3%) compared to a battery strength of ≥6 volts for 1393 (99.7%) devices. The median months active across 9 provinces ranged from 8 in the Eastern Cape to 12 (Figure 2) reported for 4 provinces (Gauteng,

Table 1. The number of results that were delivered as short message system (SMS) printers based at 2232 primary health care (PHC) facilities offering antiretroviral treatment across South Africa in the 2020 calendar year. Data is provided for the defined test repertoire. The percentage contribution is also indicated. The national test volumes are also reported for the same period to indicate the coverage of SMS-based results, which was adjusted for PHC testing.

Test	SMS results delivered (n=)	Percentage contribution	National test volumes (n=)	Percentage PHC&	National PHC test volumes (n=)	Percentage SMS coverage
HIV viral load	2,275,930	51.1	5,837,767	85.2	4,972,313	45.8
CD4 count	929,032	20.9	2,321,245	77.2	1,791,905	51.8
Xpert® MTB/RIF Ultra	570,176	12.8	1,583,746	81.4	1,288,573	44.2
Creatinine (eGFR)	239,750	5.4	11,420,638	40.0	4,568,255	5.2
HIV DNA PCR	205,997	4.6	674,246	62.4	420,574	49.0
Smear: acid-fast bacilli	97,776	2.2	674,296	40.0	269,718	36.3
Reflexed cryptococcal antigen	67,491	1.5	286,850	40.0	114,740	58.8
Hep B Surface Antigen	63,964	1.4	639,015	40.0	255,606	25.0
Total	4,450,116	100.0	23,437,803	58.4	13,681,685	45.8

SMS, short message system; HIV, Human immunodeficiency virus; eGFR, estimated glomerular filtration rate; CD4, cluster of differentiation 4; MTB, mycobacterium tuberculosis complex; RIF, rifampicin; PCR, polymerase chain reaction; PHC, primary health care; Hep, hepatitis. &Proportion of national laboratory expenditure that was allocated to PHC facility account numbers.

Table 2. Annual equivalent costs and cost per short message system (SMS) printer result delivered for an end-to-end program delivered to 2232 primary health care facilities offering antiretroviral treatment across South Africa in the 2020 calendar year. Data is provided for each cost category. The cost per SMS printer result delivered is reported to 4 decimal places.

Cost category	Annual equivalent cost (USD)	Percentage contribution	Cost per SMS printer result delivered (USD)
Staffing	$46,766.71	6.80	$0.0110
Procurement of SMS Printers	$505,613.49	73.52	$0.1190
Fixed costs related to the national SMS co-ordinator	$972.32	0.14	$0.0002
SMS consumables	$434.41	0.06	$0.0001
SMS co-ordinator travel costs	$37,385.98	5.44	$0.0088
Dashboard development, server hosting, database support, connectivity, etc.	$51,114.65	7.43	$0.0120
SMS results transmission	$45,440.26	6.61	$0.0107
Total	$687,727.81	100.00	$0.1618

SMS, short message service; USD, United States dollars.

KwaZulu-Natal, Mpumalanga, and Northern Cape). The Free State and Limpopo reported 11 median active months compared to 10 for the North West province.

Discussion and Conclusions

The objective of this study was to assess the costs, utilization, and coverage of SMS printers in South Africa. Overall, the end-to-end SMS program reported a cost of around $16 cents per result delivered. The total AEC for the SMS program was just under $700 thousand. This finding demonstrates that in the absence of electronic data systems and connectivity, the SMS printer program was able to deliver results for a low unit cost. When compared to the NHLS national test volumes from PHC facilities, the SMS printer platform was able to deliver up to half of all HIV viral load, CD4, HIV DNA PCR and Xpert® MTB/RIF Ultra results. This demonstrates that the current SMS platform was able to provide substantial coverage across South Africa. However, given the high contribution of the SMS printer to AEC would be feasible to support further deployment or an extension of the program to include additional tests. However, the clinical impact of the SMS printers may improve patient outcomes, earlier clinical management, or reduce loss to follow-up. There may be clinical cost savings that are generated by the SMS printer program, although this was not the aim of this work. A cost-effective analysis is required to assess costs and outcomes for the standard of care (paper-based) and SMS printers.

Our findings revealed that the majority of costs were contributed by the SMS printer devices. This implies that it would be difficult to further reduce the costs of the program as the non-printer contribution is less than $0.04 per result delivered. It is clear that the capital costs (SMS printer purchase) far outweigh the operational aspects of the program. Therefore, unless there is a substantial reduction in the purchase price of the SMS printer it would not be possible to reduce costs further.

However, the utilization data highlights challenges faced with the use of these SMS printers. Our findings reveal that only 70% of GDSP printers were active in the 2020 calendar year. This indicates that approximately 670 printers were not active despite the finding that high levels of signal strength and battery levels were observed. One possible explanation for this finding could be that health facilities experienced some technical challenges. From fieldwork, there is anecdotal evidence that SMS printers are unplugged to boil water during tea breaks and then not plugged in again. Furthermore, feedback from clinical trainers, that support and mentor PHC facilities, is that the majority of sites utilize both SMS printers and TrakCare WebView (internet-based results access). Analysis of WebView user statistics demonstrates a significant month-on-month increase in utilization (of up to 50%) when comparing 2020 to 2019 data (Figure 3). This confirms that TrakCare WebView is more widely available and may now be the preferred option to access results, rather than SMS-printers. This may also be facilitated by the fact that TrakCare WebView pro-

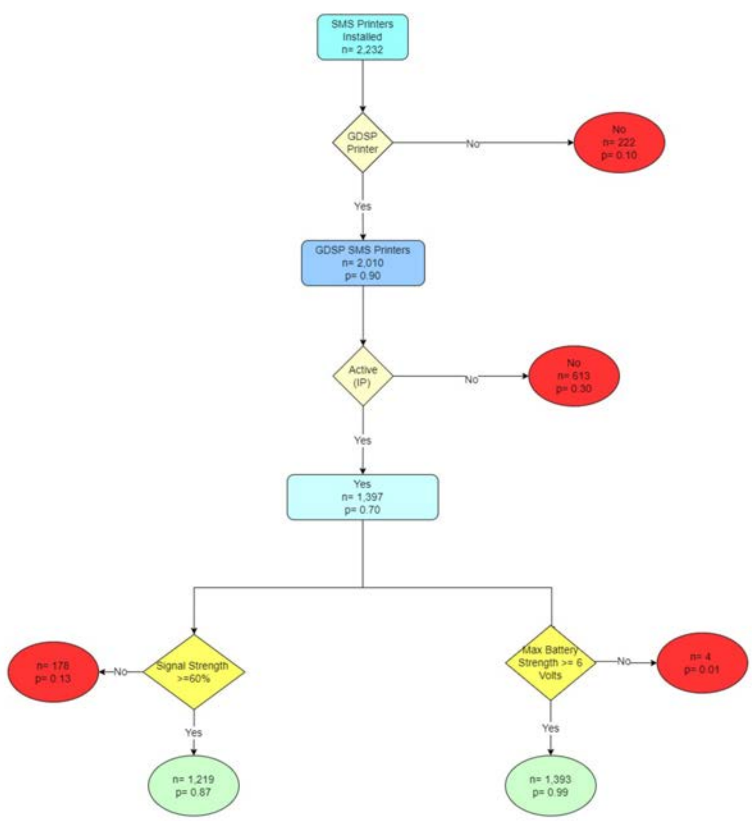

Figure 1. Flow chart depicting the number of short message system (SMS) printers placed at primary health care facilities offering antiretroviral treatment across South Africa that were using the global data service platform (GDSP). For GDSP SMS printers, the number that was active in the 2020 calendar year was reported based on the internet protocol (IP) data. Data is provided to indicate what number of active GDSP printers reported a signal strength of ≥60% and battery strength of ≥6 volts. SMS, short message service; GDSP, global data service platform.

vides access to results for all testing types whereas SMS printers offer a limited array of TB and HIV-specific test results. Findings from a Western Cape province study indicate that PHC facilities have migrated to internet-based laboratory report access using the TrakCare WebView, reducing the need for SMS printers.[10] This is a promising finding that indicates that when computers and bandwidth are provided, health facilities can migrate from SMS to web-based platforms. In addition, for health districts supported by both the Centers for Disease Control and Prevention (CDC) and President's Emergency Plan for AIDS Relief (PEPFAR), the eLABS mobile application was introduced using smartphones to provide immediate notifications of patient results to improve health system responsiveness and patient care.[11,12] The aim of the eLABS solution is to expedite the early identification of patients that are virally unsuppressed for enhanced adherence counseling.[13] The disparity in the median month's active is confirmed by data showing a shift from SMS printers to other modalities such as TrakCare WebView (Figure 3) and eLABS.

These findings indicate that the utilization of GDSP SMS printers is not determined solely by the actual devices but also by the practices at the health facility. To address this, significant health system strengthening would be necessary to guarantee that facility managers have all the necessary tools to effectively manage the printers entrusted to their care. The health system strengthening would require an enormous effort to re-train facility managers across the country as well as instill ownership and responsibility for the SMS printer in their care. Perhaps a basic SMS training module could be integrated into the regional training centers curriculum.[14,15] Master trainers at the regional training centers offer work-based training for all PHC facilities in South Africa. This finding also suggests that monitoring the utilization of SMS printers at the facility level is required as a broad programmatic assessment. This could be achieved by training using a standardized checklist and capturing their findings on the use of the SMS printers on a survey application such as RedCap.[16,17] This would make it possible to assess SMS utilization, health facility practices, and challenges and determine whether switches to other platforms are being made. Such a study would provide valuable data to guide future implementations.

The poor utilization findings contrast with the low cost to deliver an SMS-based laboratory resulting indicating a need to migrate from a paper-based to a fully electronic clinic-laboratory interface. However, challenges with the implementation of health information systems in a developing world context have been well documented.[18] This includes challenges such as information technology infrastructure and connectivity. Furthermore, this infrastructure is unevenly distributed between urban areas and rural areas.[19] There are some promising signs that, despite these challenges, there have been various electronic health record systems that have been implemented in South Africa such as Medicom, Clinicom and Tier.Net.[20-22] While Clinicom and Medicom have been implemented in hospitals, the Tier.Net and Health Patient Registration System (HPRS) applications have been implemented in PHC facilities across South Africa.[20-24] The Medicom implementation was the first in South Africa to adopt a fully electronic paperless hospital.[25] A key challenge is that even with electronic systems such as Clinicom, Tier.Net and TrakCare WebView, the clinic-laboratory interface is still paper-based. Only the Inkosi Albert Luthuli Central Hospital (IALCH) has an end-to-end electronic system across the pathology value chain. This dramatically improved the clinic laboratory interface by adopting paper-less order entry. Unfortunately, this only applies to patients admitted to the IALCH hospital, and samples from referring PHC facilities are paper-based.

Therefore, what is needed is an end-to-end electronic clinic-laboratory system that includes all processes from order entry (test request) to clinical action on the laboratory report. In a PHC setting, such a system would encompass all the following activities: i) order entry (sample acquisition); ii) courier collection; iii) sample tracking within the laboratory network; iv) laboratory report delivery; v) providing result prompts to the patient. This would ensure that all aspects of the clinic laboratory interface. There are

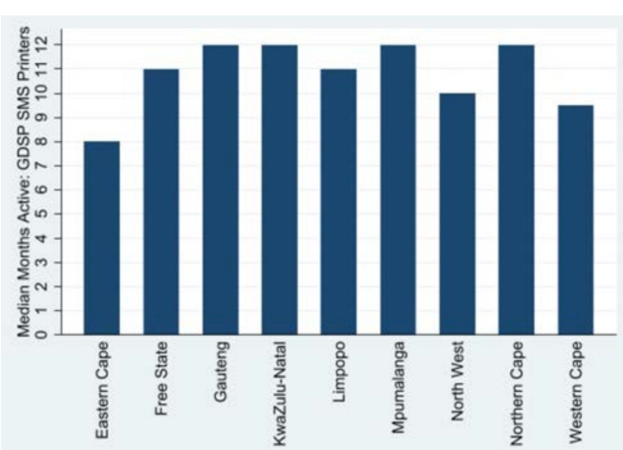

Figure 2. Bar chart reporting the median number of months during which global data service platform (GDSP) short message system printers were active in each province for the primary health care facilities offering antiretroviral treatment across South Africa in the 2020 calendar year. This was determined by analyzing the first and last transmission for all active GDSP printers. SMS, short message service; GDSP, global data service platform.

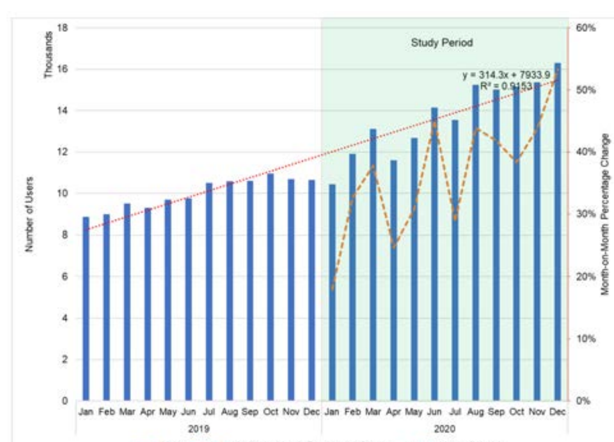

Figure 3. Number of TrakCare WebView users per month for the period between January 2019 and December 2020. The month-on-month percentage change was reported on the secondary y-axis, *i.e.*, comparing January 2019 to January 2020. This data was extracted from the laboratory information system.

many benefits to introducing such a system.

Firstly, order entry would remove the need for paper-based request forms, improve order response and minimize transcription errors.[26] It would also remove the need for the recapture of existing patient demographics and health facility information already stored in systems such as Tier.Net and HPRS.[20-22] The HCW would have to select an existing patient and indicate what laboratory tests need to be performed. This would reduce the time taken to complete the paper-based laboratory request as well as reduce transcription errors. In addition, this will improve test ordering efficiency, laboratory utilization, and ultimately patient care.[27,28] It has been documented that order entry can decrease costs, reduce medical errors, and improve compliance with clinical guidelines.[29] In addition, order entry has the potential to integrate decision support systems to limit requests to the essential laboratory list or provide disease-specific order sets to standardize care, *e.g.*, pregnant women who test HIV positive should have a CD4 (including reflex cryptococcal antigenemia) and creatinine testing performed.[30]

Secondly, the monitoring of courier collection times could be used to tailor routes such that the majority of samples are received by the source laboratory on the same day. An unpublished local study has shown that HIV viral load testing access is dependent upon the time of courier collection and that optimizing the network and delaying collection to 14h35 increased patient access to same-day blood draws by between 7 and 15%, depending on the patient-flow distribution at health facilities.[31] This courier collection data could be collated and used to further optimize the network to ensure that same-day blood draws become the standard of care.

Thirdly, sample tracking enables complete visibility from sample collection by the courier to delivery at the testing laboratory. This data can be used to identify bottlenecks in the transport and processing of samples from the health facility to the testing laboratory for targeted interventions. In addition, this data would make it possible to manage courier performance by analyzing collection and delivery times. This would also provide full visibility of all samples for a national logistics manager as samples transition from the health facility to the source and finally to the testing laboratory. This data could also be used to identify gaps in the current logistics network that could be amended by analyzing trends.

Finally, patient applications have shown that they can be used to provide HIV-related laboratory results, information, support, and appointment reminders to engage and link patients to care.[32] A good example is the iThemba Life application that showed that patients received HIV viral load results 10 times sooner than the standard of care.[33] Similarly, the miLINC suite of smartphone applications was designed to improve the time from diagnosis to treatment initiation for patients with rifampicin-resistant TB.[34] This study showed that the time from presentation to treatment initiation could be significantly improved by using an integrated approach.[34] Furthermore, another local study reported that participants were willing and able to report HIV self-testing results using mobile digital technology.[35] These studies demonstrate the maturity of patient-centric applications that outperform the paper-based standard of care. Therefore, adding a patient application to the end-to-end electronic clinic-laboratory system would make sense to improve the pathology value chain specifically for chronic diseases.

Our findings show that the SMS program improved post-analytical TAT at a very low cost per result, which was better than the paper-based systems. However, it is only able to address post-analytical aspects of the pathology value chain. It has been reported that between 46 to 68.2% of errors in the three stages of the laboratory testing process were in the pre-analytical phase.[36] Therefore, with the growing investment in health information technology infrastructure in South Africa, it would be wise to migrate from these legacy systems to an end-to-end electronic clinic-laboratory interface that would improve patient care in the pre- and post-analytical stages of the laboratory testing process and provide visibility across the pathology value chain.

Limitations

The findings reported in this study apply to all lower-middle-income countries. However, the costs reported could vary substantially based on the SMS printer used, results transmission costs, and implementation model. Moreover, some countries do not have the dashboard development, server hosting, database support, and connectivity costs reported for our study. In addition, utilization would vary based on the setting and the use of other options available for receiving laboratory results.

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