

The Role of Forensic Data Analytics in Strengthening Segregation of Duties and Expenditure Oversight in Zimbabwean Urban Local Authorities

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Abstract

This study investigates the role of forensic data analytics (FDA) in strengthening segregation of duties and expenditure oversight in Zimbabwean urban local authorities, drawing on evidence from Chitungwiza Municipality, Norton Town Council, Goromonzi Rural District Council, and Ruwa Local Board over 2020 to 2025. The research responds to a deepening financial governance crisis in the sector, evidenced by widespread failure to submit financial statements and persistent expenditure irregularities concentrated in procurement. A convergent parallel mixed-methods design combined a multi-council case study with a sector-wide survey of 198 respondents drawn from finance, internal audit, and procurement personnel, semi-structured interviews, focus groups, and the development and pilot testing of an open-source FDA prototype at Ruwa Local Board. Existing segregation of duties controls were found to be structurally inadequate, with a sector-wide mean effectiveness score of 2.63 out of 5. Multiple regression analysis incorporating FDA adoption, top management support, information and communication technology (ICT) infrastructure and data quality, local authority type, and respondent experience explained 70.0 percent of variance in segregation of duties effectiveness ($R^2 = 0.700$, $p < 0.001$), with FDA adoption the strongest predictor ($\beta = 0.524$, $p < 0.001$). The FDA prototype identified 12 additional suspicious transactions worth ZiG340,000 undetected by conventional audit. It is concluded that FDA offers a statistically validated, cost-effective pathway to strengthening internal controls in resource-constrained local government settings, provided institutional commitment and technical readiness accompany adoption.

Keywords: Forensic Data Analytics, Segregation of Duties, Internal Controls, Local Government, Zimbabwe, Expenditure Oversight

1. Introduction

Urban local authorities in Zimbabwe are the primary vehicles through which government translates policy commitments into services for millions of urban residents, including water and sanitation, road maintenance, refuse collection, housing, and local economic development, managing budgets running into

hundreds of millions of Zimbabwe Gold (ZiG) annually (Munyepwa et al., 2025) [1]; (Guti and Kurauone, 2025) [2].

Despite this role, the sector faces a deepening financial governance crisis. The Office of the Auditor-General reported that 71 percent of local authorities, 66 of 92, failed to submit financial statements for the year ended 31 December 2024 (Herald, 2025) [3]; (The Independent, 2025) [4]. The Zimbabwe Anti-Corruption Commission has identified local authorities as the country's leading corruption hotspot, with procurement fraud, payroll ghost workers, and fictitious expenditure among the most common irregularities (ZACC, 2024) [5].

This paper examines whether forensic data analytics can strengthen segregation of duties and expenditure oversight, using evidence from four councils, namely Chitungwiza Municipality, Norton Town Council, Goromonzi Rural District Council, and Ruwa Local Board, for 2020 to 2025. Both the FDA and internal control relationship are tested statistically, and a working, open-source FDA prototype tailored to the operational realities of Zimbabwean local government is developed.

1.1 Problem Statement

With 71 percent of councils failing to submit 2024 financial statements and local authorities topping the anti-corruption priority list of the Zimbabwe Anti-Corruption Commission, the sector shows accountability deficits that undermine service delivery and erode public trust. At Ruwa Local Board specifically, and similarly at Chitungwiza, Norton, and Goromonzi, internal control weaknesses persist across audit cycles: inadequate segregation of duties in expenditure processing, manual systems vulnerable to override, limited capacity for systematic transaction monitoring, and reactive rather than proactive fraud detection (Ruwa Local Board, 2024) [6]. Despite growing international evidence that FDA offers a cost-effective, scalable response to these problems, no systematic FDA framework had previously been piloted within the Zimbabwean local authority context, and this gap is addressed by the present study.

1.2 Objectives and Hypothesis

The objectives of the study were to establish the effectiveness of existing segregation of duties mechanisms, to assess patterns of expenditure irregularities for 2020 to 2025, to determine the extent to which FDA strengthens oversight of expenditure management, and to identify barriers to and enablers of FDA implementation.

H1: There is a significant positive relationship between FDA application and the effectiveness of internal controls in strengthening segregation of duties and detecting expenditure irregularities in Zimbabwean urban local authorities.

2. Literature Review

2.1 Forensic Data Analytics, Concept and Distinguishing Features

FDA is the convergence of forensic accounting, data science, and investigative procedure to detect, investigate, and prevent financial irregularities (Adeniran and Ojo, 2025) [7]; (Kang and Thosuwanchot, 2024) [8]. Unlike traditional forensic accounting, which relies on manual examination of selected samples, FDA analyses entire transaction populations, flags statistical anomalies, and generates alerts in near real time (Murinda and Chiwariro, 2023) [9]. Its principal distinguishing contribution to internal control is that it creates an independent, automated layer of transaction monitoring that functions irrespective of internal authorisation pathways, effectively separating the detection function from the operational functions of processing, authorising, and recording expenditure, and thereby reinforcing segregation of duties in

settings where full structural separation of roles is not staffing-feasible, as noted by Murinda and Chiwariro (2023) [9].

2.2 Theoretical Framework

Three theories ground the study. The Fraud Triangle of Cressey (1953) [10] identifies pressure, opportunity, and rationalisation as conditions for fraud, and FDA directly narrows the opportunity dimension by making concealment computationally detectable. Institutional Theory, as set out by DiMaggio and Powell (1983) [11], explains adoption through normative pressure from professional and International Public Sector Accounting Standards (IPSAS), coercive pressure from the Auditor-General, the Public Finance Management Act, and the Zimbabwe Anti-Corruption Commission, and mimetic pressure from peer adoption. The Technology Acceptance Model of Davis (1989) [12] frames adoption as driven by perceived usefulness and ease of use, informing both the study of implementation barriers and the design of the prototype.

2.3 Segregation of Duties and Prior Zimbabwean Evidence

Segregation of duties, which separates authorisation, recording, custody, and reconciliation, is among the most fundamental expenditure controls, requiring that no individual both initiates and approves a purchase, as noted by Murinda and Chiwariro (2023) [9]. Zimbabwean local authorities frequently fail to maintain this separation because of limited staffing, skills shortages, and deliberate circumvention (Ruwa Local Board, 2024) [6]. Nasution and Faridani (2025) [13], reviewing 52 peer-reviewed studies, found that unqualified audit opinions often mask underlying integrity flaws, since conventional audits test administrative compliance rather than substantive financial integrity.

Within Zimbabwe specifically, Munyepwa et al. (2025) [1] found forensic techniques particularly effective at detecting procurement fraud and payroll irregularities, while identifying resource constraints, political interference, and weak legal frameworks as principal barriers. Gutu and Kurauone (2025) [2], surveying 112 respondents, found a significant positive association between forensic accounting and procurement cost efficiency. Murinda and Chiwariro (2023) [9] explicitly called for data analytics tools to enhance the scalability of forensic accounting in the public sector, a call answered directly by the present study.

2.4 Comparative Evidence on Analytics-Based Fraud Detection

Adeniran and Ojo (2025) [7] demonstrated the feasibility of machine-learning fraud detection using a Random Forest classifier on asset declarations within a resource-constrained African public sector context in Nigeria. Kang and Thosuwanchot (2024) [8] found ensemble methods, particularly Random Forest and Gradient Boosting, achieving F1-scores above 0.85 in public sector fraud detection. Georgiou et al. (2024) [14] found that integrated, multi-dimensional audit systems outperform siloed audit functions.

2.5 Research Gap

While the literature establishes the value of forensic accounting in the public sector of Zimbabwe broadly, no prior study applies data analytics specifically to local authority expenditure management across a multi-council cluster to test its statistical relationship with segregation of duties effectiveness. This study moves from diagnosis to design, developing and piloting an FDA framework fitted to the Zimbabwean local authority context.

3. Methodology

A pragmatist philosophy and convergent parallel mixed-methods design were adopted (Creswell and Creswell, 2018) [15]; (Saunders et al., 2019) [16], combining a multi-council case study, namely Ruwa

Local Board, Chitungwiza Municipality, Norton Town Council, and Goromonzi Rural District Council, with a sector-wide survey, bounded by time (2020 to 2025), organisation type, and substantive focus. A design-science component followed the iterative develop, evaluate, and refine cycle recommended by Hevner et al. (2004) [17] for prototype development.

Using the formula of Yamane (1967) [18] at 95 percent confidence and a 5 percent margin of error, a target of 75 local authorities was sampled by stratified random sampling, by type and province, with three respondents per authority, namely a finance manager, an internal auditor, and a procurement officer, yielding a target of 225. A total of 198 questionnaires were returned, an 88 percent response rate. Fourteen semi-structured interviews were conducted at Ruwa Local Board, with additional key informants at the other three councils, alongside two focus groups, one with finance staff (n=8) and one with audit and procurement staff (n=7).

Data collection instruments comprised systematic document review of internal control policies, audit reports for 2020 to 2025, Auditor-General reports, and procurement records; a seven-section structured questionnaire using five-point Likert scales covering irregularity patterns, control effectiveness, FDA awareness and perceived impact, institutional readiness, and barriers and enablers; semi-structured interviews and focus groups; and development of an open-source FDA prototype, built in Python and R, applied to four years of Ruwa Local Board transaction data, comprising five modules, namely Benford's Law analysis, duplicate payment detection, vendor concentration analysis, authorisation pathway and segregation of duties mapping, and temporal pattern analysis, piloted over four weeks with the internal audit team.

Descriptive statistics, Pearson correlation, multiple regression, and Structural Equation Modelling were used for quantitative data, and the six-phase thematic analysis of Braun and Clarke (2021) [19] was used for qualitative data, with joint-display integration at the interpretation stage. Reliability and validity were supported through triangulation, member checking, a case study protocol, and internal consistency testing. Ethical clearance was obtained from the Research Ethics Committee of the Harare Institute of Technology, with institutional permission from all four councils and the Ministry of Local Government, informed consent, and pseudonymisation of participants.

4. Findings

4.1 Participant Profile

Of the 198 respondents, 31.8 percent were from local boards, 31.8 percent from municipal councils, 24.2 percent from town councils, and 12.1 percent from city councils. Roughly equal thirds were finance managers, internal auditors, and procurement officers. Some 79.3 percent had more than five years of experience, and 80.8 percent held a bachelor's degree or higher.

4.2 Expenditure Irregularity Patterns

Document review across all four councils identified six recurring irregularity categories, concentrated overwhelmingly in procurement, accounting for 63 percent of cases by frequency and 71 percent by value. At Ruwa Local Board, unauthorised expenditure, 58 instances, and procurement without competitive quotation, 47 instances, were most frequent by count, while procurement without competitive quotation carried the largest financial impact, ZiG2,300,000. Chitungwiza exhibited the highest volume of procurement irregularities, attributed to transaction volume and a contested oversight environment. Norton's audits highlighted order-splitting as the dominant circumvention method, and Goromonzi showed more prevalent payroll irregularities, reflecting weaker human resources and finance interface controls.

Applying Benford's Law to 14,827 Ruwa Local Board transactions revealed statistically significant digit-distribution deviations for procurement payments (chi-square, $p < 0.01$), with excess clustering just below authorisation thresholds, namely United States dollar (USD) 9,000 to 9,999 and USD49,000 to 49,999, providing independent statistical corroboration of systematic order-splitting.

Sector-wide, survey respondents rated procurement without competitive quotation, mean 3.87 out of 5, and payments lacking adequate documentation, mean 3.74, as the most frequent irregularities, consistent with the document review findings. A Finance Director observed in interview that controls are formally present but bypassed daily through urgency claims, management override, and unfamiliarity with procurement regulations.

4.3 Effectiveness of Existing Internal Controls

Across six control dimensions, no category achieved a mean above 3.12 out of 5, indicating broad, cross-council consensus that existing controls, including segregation of duties, are inadequate. Segregation of duties in payment authorisation scored a mean of 2.63. A significant difference emerged by authority type ($F = 4.23$, $p = 0.006$), with city councils rating controls higher than local boards, though even city councils rated all dimensions below the midpoint of 4.0 taken to indicate an effective control. An internal auditor described the core failure as follows: formal procurement committees and thresholds exist, but in practice the Finance Director can approve payments unilaterally when claiming urgency, and there is no mechanism to challenge this in real time.

4.4 FDA and Segregation of Duties and Oversight

Over the four-week pilot, the prototype generated 198 alerts across five modules, comprising 87 from Benford's Law deviations, 58 from segregation of duties and authorisation pathway failures, 31 duplicate payment flags, 12 temporal anomaly flags, and 10 vendor concentration flags, with three vendors accounting for 38 percent of procurement spend and seven suspended vendors found in active payment records. The authorisation pathway module found 58 payment instances lacking an independent authorisation chain. Critically, the system surfaced 12 additional suspicious transactions, combined value ZIG340,000, that had not been identified by conventional audit procedures.

Survey respondents rated the potential impact of FDA highly across all five dimensions, means 3.89 to 4.23, with the strongest agreement on improved detection of duplicate payments, 4.23, and improved audit evidence quality, 4.18. Structural Equation Modelling confirmed a significant positive path from FDA application to segregation of duties and internal control effectiveness ($\beta = 0.67$, $p < 0.001$; comparative fit index = 0.94; root mean square error of approximation = 0.058), supporting H1.

4.5 Correlation and Regression Analysis

Pearson correlations, all $p < 0.01$, showed FDA adoption most strongly associated with segregation of duties effectiveness ($r = 0.67$), expenditure oversight ($r = 0.64$), and procurement compliance ($r = 0.61$). Top management support ($r = 0.52$) and ICT infrastructure and data quality ($r = 0.49$) were also significantly correlated with FDA adoption, and both correlated strongly with segregation of duties effectiveness, $r = 0.58$ and $r = 0.55$ respectively.

A five-predictor multiple regression, with segregation of duties effectiveness as the dependent variable, was statistically significant overall ($F(5,192) = 89.64$, $p < 0.001$), explaining 70.0 percent of variance ($R^2 = 0.700$, adjusted $R^2 = 0.692$). Table 1 presents the regression coefficients.

Table 1: Multiple Regression Coefficients, Predictors of Segregation of Duties Effectiveness

Predictor	Standardised Beta	t	Significance
FDA Adoption Index	0.524	9.373	< 0.001
Top Management Support	0.281	6.500	< 0.001
ICT Infrastructure and Data Quality	0.241	5.872	< 0.001
Local Authority Type	0.111	2.262	0.025
Years of Experience	0.083	1.972	0.049

FDA adoption was the strongest predictor, with top management support and ICT infrastructure and data quality as substantial secondary predictors. Diagnostics confirmed model adequacy, with a Durbin-Watson statistic of 1.95 indicating no autocorrelation, all variance inflation factors well below 5, in the range 1.06 to 1.24, indicating no problematic multicollinearity, and residuals approximately normal and homoscedastic. The null hypothesis is accordingly rejected.

4.6 Barriers and Enablers

Technical skills and capacity was the most severe barrier, mean 4.31 out of 5, followed by financial resources, 4.18, and data quality, 4.12. Political and institutional resistance, though rated lower, 3.87, was described qualitatively as potentially the most consequential, with one focus group participant observing that the technical problems can be solved with training and tools, but if senior management do not want the scrutiny FDA would bring, they will find ways to obstruct it. Key enablers were regulatory pressure from the Auditor-General and the Ministry of Local Government, cited by 78 percent of respondents, open-source tooling that eliminates licensing costs, 71 percent, and peer learning across councils, 67 percent.

5. Discussion and Conclusions

Four conclusions follow. First, expenditure irregularities across the sector are systemic rather than isolated, concentrated in procurement, and directly detectable through FDA techniques, and the identification by the prototype of ZiG340,000 in previously undetected irregularities demonstrates the superior detection power of FDA relative to conventional audit. Second, existing segregation of duties frameworks constitute a structural accountability deficit, with mean effectiveness below 3.0 across all relevant control dimensions, compounded by routine management override of documented controls. Third, the statistical evidence, $\beta = 0.524$, $R^2 = 0.700$, and the Structural Equation Modelling path coefficient of 0.67, provides robust support for treating FDA adoption as a significant driver of improved segregation of duties effectiveness, independent of council size or respondent seniority, elevating FDA from a theoretical proposition to an evidence-based governance tool. Fourth, implementation barriers, while real, are not insurmountable, since the open-source prototype shows that functional FDA capability is deployable without commercial licensing, and institutional enablers, namely regulatory mandate, peer learning, and open-source tooling, provide a viable adoption pathway, provided political will accompanies technical readiness.

6. Recommendations

For local authority management, it is recommended that open-source FDA modules be piloted, starting

with Benford's Law and duplicate payment detection, that authorisation pathway mapping be embedded into payment workflows with automatic escalation alerts, and that cross-council peer learning networks be formalised.

For the Auditor-General's Office, it is recommended that FDA-generated evidence, including Benford's Law results, duplicate payment reconciliations, and vendor concentration analyses, be mandated as supporting schedules to annual financial statements, and that standardised FDA performance indicators be developed for audit quality assessment.

For the Ministry of Local Government and Public Works, it is recommended that Public Finance Management Act regulations be gazetted requiring FDA-capable monitoring above defined budget thresholds, phased by council type, and that a ring-fenced digital governance fund be established for the capacity building of smaller councils.

For the Institute of Chartered Accountants of Zimbabwe, it is recommended that an accredited Local Authority FDA Practitioner Certificate be developed and that FDA competencies be integrated into public sector continuing professional development requirements.

For future research, longitudinal tracking of FDA implementation outcomes on audit opinion quality is recommended, together with extension of the study to rural district councils and the development of Zimbabwe-specific machine learning fraud indicators, including currency-switching transactions, threshold-proximity clustering, and vendor network analysis.

7. Contribution to Knowledge

This study extends Fraud Triangle, Institutional, and Technology Acceptance theory to FDA adoption in African local government, provides the first multi-council regression evidence of a statistically significant relationship between FDA and segregation of duties in the local authority sector of Zimbabwe, and delivers a functional, directly implementable open-source FDA prototype suited to Zimbabwean operational realities.

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