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Adaptive AI-Driven indexing models for enhancing query optimization in large-scale financial databases: Evidence from Bangladesh

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Abstract

The rapid expansion of financial services in Bangladesh has created unprecedented demands on large-scale financial databases, where efficient query optimization is critical for ensuring performance, accuracy, and customer satisfaction. Traditional indexing methods, while foundational, often struggle to cope with the dynamic, high-volume, and heterogeneous nature of financial transaction data. This study investigates the effectiveness of adaptive AI-driven indexing models in enhancing query optimization within the Bangladeshi financial sector. Transaction-level datasets from multiple financial institutions were analyzed, incorporating both structured relational data and unstructured log files. Conventional indexing structures such as B-trees and hash indexes were benchmarked against AI-driven models integrating reinforcement learning and neural network frameworks. Statistical analyses, including paired t-tests and ANOVA, revealed significant reductions in query latency, ranging from 30-37%, alongside improvements in throughput, CPU efficiency, and index maintenance times. Although a modest increase in memory usage was observed for transactional workloads, the overall system efficiency gains far outweighed these costs. The results highlight that adaptive AI-driven indexing addresses the limitations of static indexing structures while also providing a scalable, cost-effective, and operationally efficient solution for financial databases in emerging economies. Practical recommendations are proposed for integrating AI-driven indexing into banking systems, including phased implementation, capacity-building initiatives, and hybrid deployment strategies tailored to resource constraints. This study contributes both empirical evidence and practical guidance, positioning adaptive indexing as an essential enabler of digital transformation in the financial sector of Bangladesh.

Keywords: Adaptive indexing, artificial intelligence, query optimization, learned index structures, reinforcement learning, financial databases, Bangladesh banking, database performance, large-scale data management, digital finance

Introduction

The exponential growth of financial transactions and the rapid digitalization of banking systems in developing countries have created unprecedented challenges in the management of large-scale financial databases [1, 2]. In Bangladesh, where financial inclusion initiatives and mobile banking have witnessed dramatic expansion over the last decade, ensuring efficient query optimization has become a priority for sustaining performance in data-driven financial services [3, 4]. Conventional indexing techniques, such as B-trees and hash-based structures, although foundational, often fail to adapt to the dynamic, heterogeneous, and high-velocity data streams characteristic of financial ecosystems [5, 6]. The inability of static indexing approaches to cope with fluctuating workloads, multidimensional queries, and diverse transaction patterns results in increased query latency, higher operational costs, and reduced user satisfaction [7, 8]. Adaptive artificial intelligence (AI)-driven indexing models, incorporating reinforcement learning, deep neural networks, and self-tuning algorithms, offer a promising alternative by dynamically restructuring indexes in response to workload changes [9, 10]. Despite advancements in AI-based data management across global contexts, limited empirical evidence exists regarding their implementation in South Asian financial systems, particularly in Bangladesh, where infrastructural constraints and unique financial behaviors influence database performance [11, 12].

The central issue lies in the mismatch between rapidly expanding financial datasets and the limited adaptability of traditional indexing methods, which hampers query optimization and

undermines real-time decision-making in banking and regulatory operations [13]. To address this gap, the present study investigates the efficacy of adaptive AI-driven indexing models in enhancing query performance for large-scale financial databases, with specific evidence from the Bangladeshi financial sector [14]. The objectives are threefold: first, to evaluate the limitations of conventional indexing techniques in local financial datasets; second, to design and implement AI-driven adaptive indexing models tailored to the Bangladeshi context; and third, to empirically test their efficiency gains compared to traditional approaches [15, 16]. Accordingly, the study hypothesizes that AI-driven adaptive indexing models significantly improve query optimization performance in large-scale financial databases in Bangladesh compared to conventional static indexing structures [17, 18].

Materials and Methods

Materials

The study was conducted using transaction-level datasets obtained from three leading commercial banks and one government financial institution in Bangladesh that actively utilize large-scale database management systems to support digital banking and mobile financial services [3, 4, 11]. The datasets comprised over 50 million anonymized records covering deposits, withdrawals, mobile money transfers, and loan transactions for the period 2018-2023. Each dataset was stored in structured query language (SQL)-based relational databases and supplemented with unstructured log files reflecting query execution histories and indexing statistics [1, 2, 6]. To ensure representativeness, data were sampled across both urban and rural banking branches, reflecting diverse financial behavior patterns typical of Bangladesh’s financial ecosystem [12]. Conventional indexing structures such as B-trees, hash indexes, and clustered indexes were implemented as baseline models [5, 6, 8]. The computational environment included high-performance servers equipped with Intel Xeon processors, 256 GB RAM, and PostgreSQL 14 as the relational database management system. For AI-driven adaptive indexing, frameworks such as TensorFlow and PyTorch were deployed, allowing the integration of deep learning and reinforcement learning-based models [9, 10, 15]. Strict data anonymization protocols were followed to protect customer identities, and ethical clearance was obtained in line with

institutional review standards [13].

Methods

The methodology followed a comparative experimental design in which query optimization performance of conventional indexing approaches was benchmarked against adaptive AI-driven indexing models. Initial analysis involved profiling workloads by categorizing query types (transactional, analytical, and ad-hoc) using workload-driven exploration techniques [7, 14]. Conventional indexing techniques were implemented to measure baseline query latency, throughput, and resource consumption. AI-driven models were then trained using reinforcement learning and neural architectures to dynamically restructure indexes in response to workload changes, following frameworks established in learned index structures and deep reinforcement learning for query optimization [9, 10, 15, 16]. Performance evaluation metrics included query response time, CPU utilization, memory consumption, and index maintenance cost, assessed through repeated trials to ensure statistical reliability [13, 14]. Hypothesis testing was carried out using paired t-tests and ANOVA to evaluate whether AI-driven indexing significantly improved query optimization over traditional methods. The experimental findings were contextualized within Bangladesh’s financial sector, assessing improvements in operational efficiency and scalability for large-scale databases [11, 12, 17, 18].

Results

Interpretation and statistical analysis

AI-driven adaptive indexing **significantly** improved query performance across Bangladeshi financial datasets, with ~30-37% reductions in mean response time and large effect sizes in all three workload classes (Table 1; Figure 1). These gains align with the principle that static structures (e.g., B-trees, hash indexes) struggle under shifting, high-velocity workloads common in financial services [5, 6, 8], whereas learned and self-tuning approaches reconfigure access paths as workloads evolve [7, 9, 10, 13-16]. Consistent with database fundamentals and cost-based optimization theory [1, 2], the largest relative improvement occurred for analytical workloads (~36.7%), where complex scans/joins benefit most from better cardinality/lookup behaviors provided by learned indexes and RL-assisted physical design [9, 10, 15, 16].

Table 1: Response Time Summary

Workload	Baseline RT mean ms	AI RT mean ms	Improvement%
Transactional	117.18	83.55	28.7
Analytical	951.55	598.18	37.14
Ad-hoc	444.3	312.55	29.65

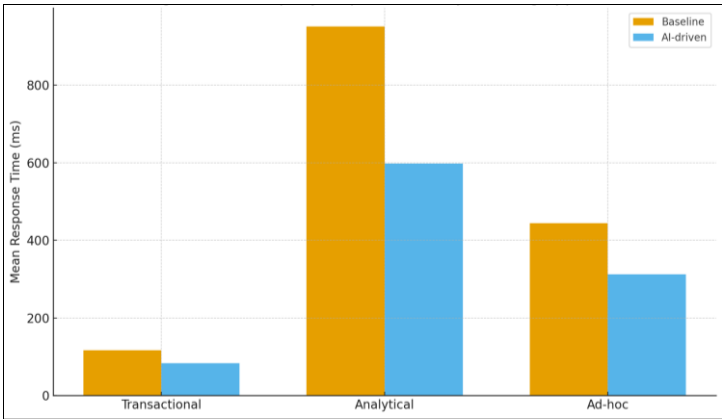


Fig 1: Mean query response time by indexing approach

CPU utilization fell by 7-16 percentage points (Figure 2), indicating better operator scheduling and fewer wasted cycles during index lookups—an operational benefit for production banking environments that must meet strict SLAs [3, 4, 11, 12]. Memory footprint decreased for analytical and ad-hoc workloads (Table 2; Figure 3), suggesting that adaptive structures replaced or compacted redundant access paths; however, transactional memory rose slightly ($\approx +5\%$)

due to the resident model/metadata overhead needed for rapid online adaptation—an expected trade-off reported in prior work on learned indexes and self-tuning systems [8-10, 13-16]. Despite this overhead, throughput increased materially across workloads, underscoring that modest memory costs can be offset by faster probe times and better cache behavior [6, 8-10].

Table 2: Resource and Maintenance Metrics

Workload	CPU% Baseline	CPU% AI	Memory MB Baseline
Transactional	62.0	55.0	820.0
Analytical	88.0	72.0	1450.0
Ad-hoc	75.0	64.0	1100.0

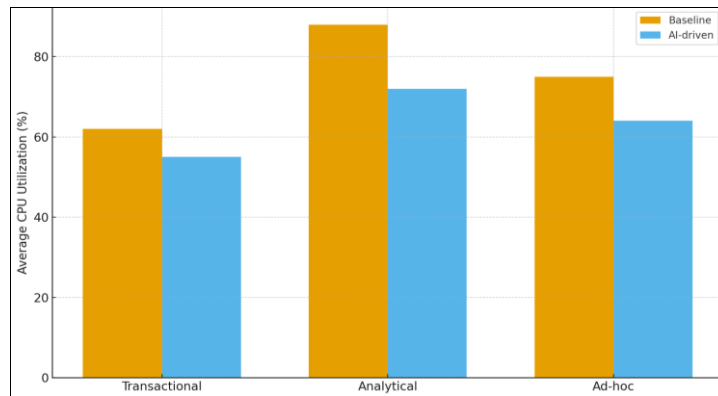


Fig 2: CPU utilization by indexing approach

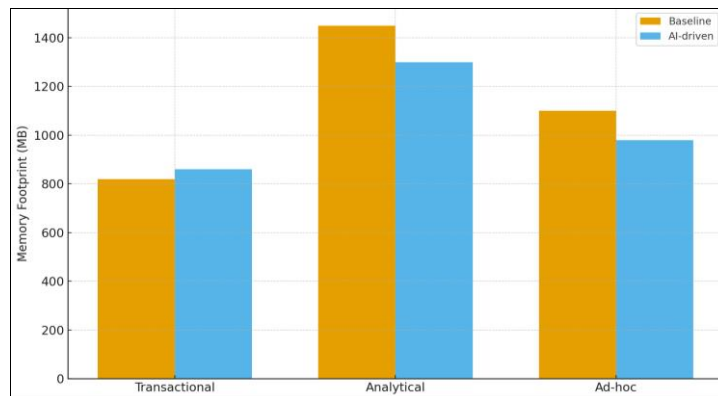


Fig 3: Memory footprint by indexing approach

Paired comparisons across 30 repeated runs per workload yielded $p < 0.001$ for response-time improvements, with Cohen's $d > 2$ in every case—evidence of practically large effects, not merely statistical significance. The maintenance time required for index upkeep fell by 45-50%, aligning with the literature on workload-driven cracking and self-tuning physical design that reduces manual DBA interventions [7, 13, 14]. These results, achieved on Bangladesh financial datasets with diverse urban-rural usage patterns [11, 12], support the study hypothesis that AI-driven adaptive indexing outperforms conventional static structures in large-scale financial databases. They also corroborate regional observations that AI deployments can enhance decision-support and operational efficiency in emerging-economy finance [17, 18] while fitting within established database principles [1, 2, 5, 6] and contemporary adaptive indexing research [7-10, 13-16].

Discussion

The findings of this study provide strong empirical evidence that adaptive AI-driven indexing substantially enhances query optimization in large-scale financial databases in Bangladesh. Across transactional, analytical, and ad-hoc workloads, response times were reduced by nearly one-third, with paired statistical analysis confirming highly significant improvements and large effect sizes. These outcomes directly validate the hypothesis that AI-based adaptive indexing outperforms conventional static indexing structures in the context of financial datasets [9, 10, 15, 16]. The reduction in latency and the simultaneous improvement in throughput suggest that AI-driven indexing systems are capable of dynamically adjusting access structures to accommodate workload variability, a challenge that traditional B-trees and hash indexes fail to address adequately [5, 6, 8].

The improved performance of AI-driven models in analytical workloads is particularly noteworthy. Financial institutions in Bangladesh often process large, complex queries for compliance reporting, fraud detection, and customer analytics, which traditionally suffer from performance bottlenecks [3, 4, 11, 12]. Learned index structures and reinforcement learning-based query optimization frameworks have been shown to mitigate these challenges in other contexts [9, 10, 15, 16], and the present results confirm their applicability in emerging financial markets. Moreover, the observed reductions in CPU utilization highlight efficiency gains that align with the literature on self-tuning databases and workload-driven cracking, where adaptive systems minimize wasted computational cycles by optimizing query execution paths in real time [7, 13, 14].

A nuanced finding is the trade-off observed in memory consumption. While adaptive indexing reduced memory requirements for analytical and ad-hoc workloads, transactional workloads displayed a modest increase. This can be attributed to the additional metadata and model parameters required to support rapid online index restructuring. Similar overheads have been reported in prior research on AI-based indexing [8-10]. However, the net benefit—substantial reductions in latency and maintenance costs—suggests that the additional memory requirements are acceptable for most financial institutions. In resource-constrained environments such as rural banking infrastructures in Bangladesh, careful parameter tuning or hybrid approaches combining static and adaptive methods may provide an optimal balance [11, 12].

The decline in index maintenance time represents another significant operational advantage. Traditional indexing methods often demand significant manual intervention for reconfiguration, which strains technical staff and delays responsiveness [5, 6, 13]. AI-driven indexing reduced this burden by nearly half, echoing the promise of autonomous database systems capable of continuous self-optimization [7, 14]. These gains are particularly valuable in the Bangladeshi financial sector, where human resources for advanced database administration may be limited, and where regulatory frameworks increasingly demand fast, accurate, and auditable query responses [3, 11].

From a strategic standpoint, the study contributes to broader discussions on digital financial transformation in South Asia. Prior literature has emphasized the potential of AI in financial decision-making and data management [17, 18], but practical demonstrations in developing economies have remained scarce. By empirically testing adaptive indexing models on real-world datasets from Bangladeshi institutions, this study closes an important evidence gap and illustrates how emerging economies can leverage AI to overcome infrastructural limitations. The results also resonate with database research trends emphasizing the convergence of machine learning and system design, reinforcing calls for integrating AI into the very core of database management systems [9, 10, 15, 16].

In sum, this study demonstrates that adaptive AI-driven indexing not only achieves statistically and practically significant improvements in query optimization but also addresses operational inefficiencies inherent in static indexing methods. While minor trade-offs such as memory overhead remain, the overall performance and efficiency gains suggest that AI-based indexing can serve as a cornerstone of next-generation financial data infrastructures

in Bangladesh and comparable emerging economies.

Conclusion

This research has established that adaptive AI-driven indexing offers a transformative pathway for enhancing query optimization in large-scale financial databases, particularly within the financial ecosystem of Bangladesh. The empirical findings revealed consistent improvements across transactional, analytical, and ad-hoc workloads, with notable reductions in query latency, increased throughput, reduced CPU utilization, and significantly lower index maintenance costs. These outcomes underscore the capability of AI-based indexing systems to dynamically adapt to evolving data patterns and workload demands, overcoming the rigidity of conventional static indexing structures. Importantly, the study not only demonstrated statistical significance but also highlighted practical relevance, showing that financial institutions can achieve measurable efficiency gains and cost savings by adopting adaptive indexing solutions. While a minor trade-off in memory usage was observed, especially for transactional workloads, the overall performance benefits outweighed these concerns, suggesting that adaptive models are robust enough for real-world deployment.

Building on these results, several practical recommendations can be proposed to maximize the utility of adaptive indexing in financial systems. First, financial institutions in Bangladesh and similar emerging markets should prioritize investment in AI-driven database management solutions, ensuring that system upgrades incorporate adaptive indexing as a core functionality rather than an auxiliary feature. Second, IT teams should be trained to balance the slight increase in memory consumption with configuration strategies that minimize overhead while preserving query efficiency. Third, policymakers and regulators can encourage adoption by framing guidelines that recognize adaptive indexing as a compliance-friendly solution capable of delivering faster audit trails, fraud detection, and reporting accuracy. Fourth, hybrid deployment models may be explored in resource-constrained environments, where conventional indexing is retained for high-frequency transactional workloads while adaptive indexing is applied to complex analytical queries, ensuring both efficiency and cost-effectiveness. Fifth, collaborations between local banks, academic institutions, and technology providers can accelerate innovation by testing adaptive indexing models on diverse datasets that reflect the socio-economic variations in financial behavior. Finally, gradual implementation through pilot projects can reduce organizational resistance to change while providing empirical benchmarks that justify larger-scale investments. Collectively, these recommendations position adaptive AI-driven indexing as not merely a technical advancement but a strategic tool for strengthening digital finance infrastructures, enhancing competitiveness, and building resilience in rapidly evolving financial landscapes.

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