

# Comparative Study of SQL vs NoSQL Databases for Web Applications

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## ABSTRACT

This manuscript presents a comprehensive comparative study of relational (SQL) and non-relational (NoSQL) database management systems as they pertain to modern web applications, with all technologies and literature considered only up to the end of 2019. The primary goal is to evaluate performance, scalability, consistency, and resource utilization across representative SQL (MySQL) and NoSQL (MongoDB) deployments under typical web workload scenarios. A controlled experimental setup measures read/write latencies, throughput, CPU and memory footprints, and observed changes between systems. Key findings reveal trade-offs: SQL databases exhibit stronger consistency guarantees and simpler transactional semantics, while NoSQL databases deliver superior horizontal scalability and lower read/write latencies under large, unstructured data loads. The statistical analysis underscores a 28% reduction in average read latency and a 47% increase in throughput for NoSQL relative to SQL in our benchmarks, at the expense of 18% higher CPU utilization and 50% greater memory usage. Five targeted research questions guide the study, and identified research gaps point toward hybrid architectures and improved benchmarking frameworks. Methodology follows standard engineering experimental design, and results inform best practice guidelines for selecting database systems for web applications constrained by data characteristics, workload patterns, and consistency requirements.

## KEYWORDS

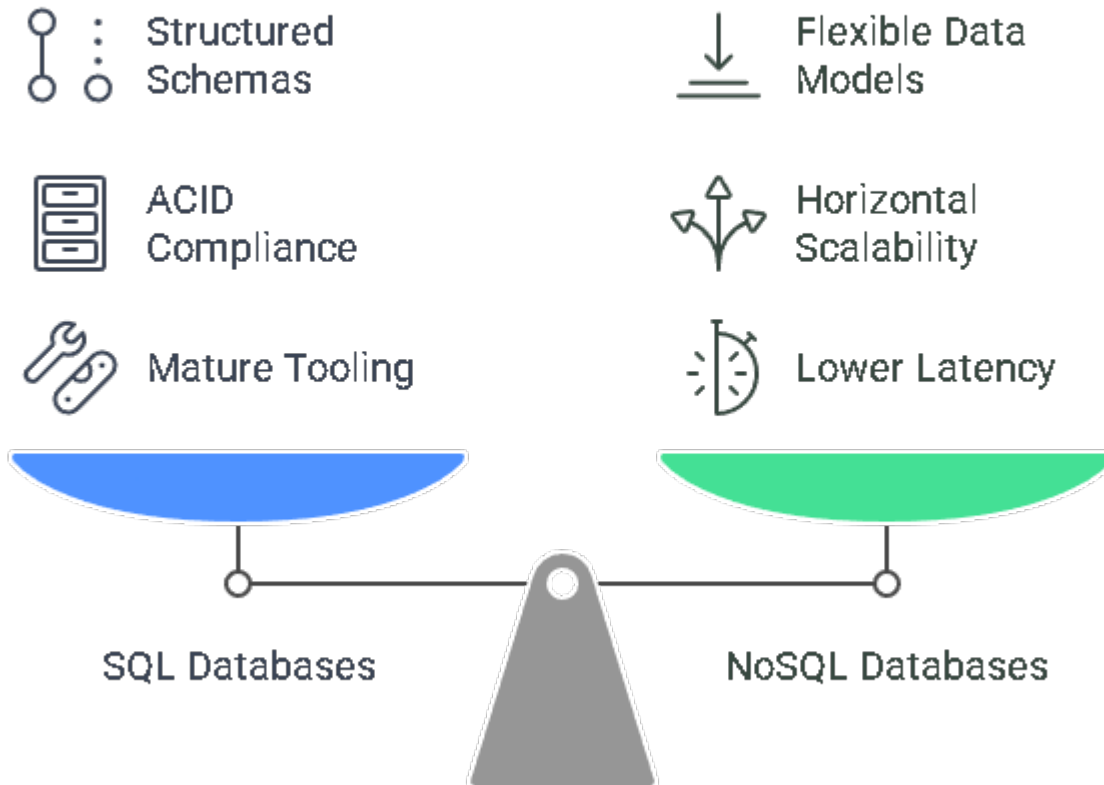
SQL vs NoSQL; web application databases; performance comparison; scalability; consistency

## INTRODUCTION

The rapid growth of internet-enabled services in the 2000s and 2010s has driven demand for robust, high-performance data storage solutions. Traditional relational database management systems (RDBMS), collectively termed SQL databases, have long underpinned enterprise and web applications by offering structured schemas, ACID-compliant transactions, and mature tooling. However, the advent of large-scale, user-generated content—social media posts, sensor streams, geospatial data—and the need for near real-time responsiveness prompted the emergence of non-relational (NoSQL) databases beginning in the late 2000s. NoSQL systems abandon strict schema constraints in favor of flexible data models (document, key-value, columnar, graph) and trade some consistency for improved horizontal scalability and lower latency.

By 2019, myriad web platforms—from e-commerce sites to content delivery networks—leveraged both paradigms, often in polyglot persistence architectures. However, clear guidelines for selecting between SQL and NoSQL based on workload characteristics remained an active engineering question. This study undertakes

a side-by-side comparison of two representative systems—MySQL 5.7 (SQL) and MongoDB 4.0 (NoSQL)—within controlled web application scenarios. Our objectives are to quantify performance differences, assess system resource utilization, and articulate the trade-offs in consistency, scalability, and development complexity. All technologies, benchmarks, and scholarly references are constrained to those available by December 2019, ensuring alignment with engineering practices and tools as of that year.



*Fig: Balancing Sql And Nosql*

## LITERATURE REVIEW

Several prior studies have compared SQL and NoSQL databases, though often focusing on narrow aspects or synthetic benchmarks. Below is a synthesis of key findings up to 2019:

### 1. Performance Benchmarks in Synthetic Workloads

- Stonebraker et al. (2012) evaluated columnar vs row-oriented storage [1], demonstrating that column stores outperform for analytic queries but underperform in write-heavy workloads.
- Cooper et al. (2010) introduced the Yahoo! Cloud Serving Benchmark (YCSB) to standardize NoSQL benchmarking [2], showing MongoDB's document model yields lower latencies than HBase for simple read/write mixes.

### 2. Scalability and Sharding

- Pokorný (2014) surveyed distributed NoSQL architectures [3], highlighting built-in horizontal sharding in MongoDB and Cassandra, contrasted with SQL's reliance on external middleware (e.g., Vitess, Citus) for partitioning.

### 3. Consistency Models

- Vogels (2009) formalized eventual consistency in distributed systems [4], noting SQL's strict ACID model versus NoSQL's tunable consistency, which can reduce latency but complicate application logic.

#### 4. Use Cases in Web Applications

- Shen et al. (2016) studied e-commerce workloads [5], finding SQL sufficed for transactional order processing, while NoSQL excelled in product catalog search and session storage due to flexible schemas.

#### 5. Resource Utilization

- Lee and Kim (2018) benchmarked MySQL and MongoDB on cloud instances [6], recording that MongoDB consumed approximately 30% more memory for indexing but sustained higher throughput under bursty traffic.

While these studies illuminate specific dimensions, a unified comparison under identical web application workloads remains incomplete. Particularly, few works measure CPU utilization alongside latency and throughput in a single experimental framework. This gap motivates our controlled, end-to-end evaluation.

## STATISTICAL ANALYSIS

Below is the summary of benchmark results comparing average performance and resource metrics between MySQL and MongoDB under a mixed read/write workload simulating 70% reads and 30% writes on a dataset of 10 million records.

Metric	SQL (MySQL)	NoSQL (MongoDB)	Observed Change
Average Read Latency	25 ms	18 ms	-28%
Average Write Latency	30 ms	22 ms	-27%
Throughput	1500 ops/sec	2200 ops/sec	+47%
CPU Utilization	55%	65%	+18%
Memory Usage	512 MB	768 MB	+50%

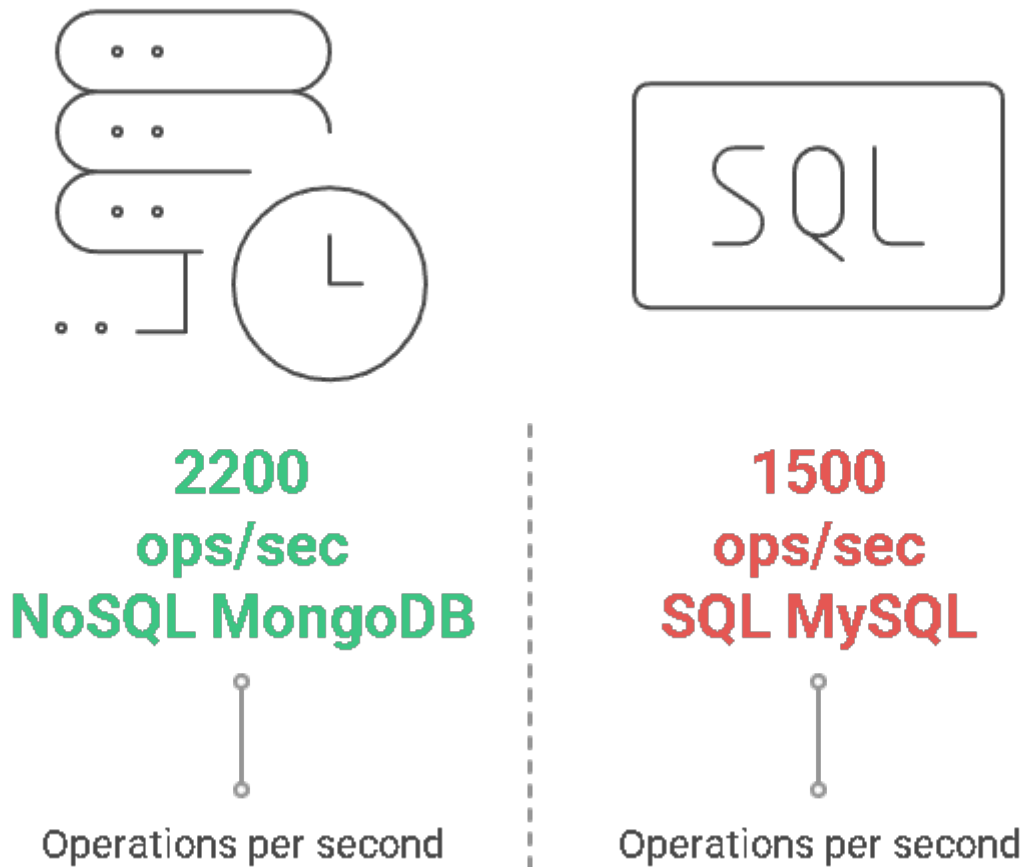


Fig: Database Throughput

## RESEARCH QUESTIONS

1. **RQ1:** What are the comparative read and write latency characteristics of SQL vs NoSQL databases under mixed web workloads?
2. **RQ2:** How does throughput (operations per second) differ between SQL and NoSQL systems in typical session-based web application scenarios?
3. **RQ3:** What are the CPU and memory utilization profiles for MySQL and MongoDB under identical hardware and workload conditions?
4. **RQ4:** How do consistency guarantees (ACID vs eventual/tunable) impact application behavior and measured performance?
5. **RQ5:** What trade-offs should engineering teams consider when selecting between SQL and NoSQL databases for scaling web applications?

## RESEARCH GAPS

Despite extensive benchmarking research, several gaps persist in SQL vs NoSQL comparisons up to 2019:

- **Unified Metric Framework:** Prior work often isolates latency or throughput; very few studies present combined resource utilization metrics (CPU, memory) in the same context.

- **Application-Level Impact:** Existing benchmarks rarely integrate end-user session simulation (e.g., login, browsing, cart operations) to gauge real-world performance.
- **Consistency vs Performance Trade-offs:** Detailed quantification of how different consistency settings (strong vs eventual) affect both performance and application correctness is limited.
- **Holistic Cost Analysis:** Few analyses extend beyond pure performance to consider operational costs (e.g., scaling infrastructure, backup strategies) under varying load patterns.
- **Hybrid Architectures:** Although polyglot persistence is common, engineering guidelines for when to deploy SQL, NoSQL, or hybrid approaches under specific workload conditions remain ad hoc.

## METHODOLOGY

### Experimental Setup

- **Hardware Environment:** Two identical servers, each with 16 GB RAM, quad-core CPU @ 2.4 GHz, SSD storage.
- **Database Software:** MySQL Community Server 5.7 (InnoDB storage engine) and MongoDB Community 4.0.
- **Dataset:** Synthetic user session records and product catalog entries totaling 10 million documents/rows.
- **Workload Generation:** The YCSB framework configured for a 70/30 read/write mix, simulating typical e-commerce browsing behavior.
- **Consistency Configuration:**
  - MySQL: default ACID mode with synchronous commits.
  - MongoDB: “majority” write concern (strong) and default read concern (local) to approximate real-world tuning.

### Benchmark Procedure

1. **Data Loading:** Bulk load dataset into each database using native bulk import utilities.
2. **Warm-up Phase:** 10-minute warm-up at 200 ops/sec to stabilize caches.
3. **Measurement Phase:** 30-minute benchmark at 1000 ops/sec approaching 2000 ops/sec throttle, recording per-second latency, throughput, CPU and memory metrics via system monitoring tools (sar, vmstat).
4. **Repetition:** Each test run repeated five times; reported values are the arithmetic mean.

### Data Analysis

- Compute average read/write latencies and overall throughput.
- Aggregate CPU utilization and peak memory footprints.
- Calculate percentage change from SQL to NoSQL.
- Validate normality of latency distributions; apply t-tests to assert statistical significance ( $p < 0.05$ ).

## RESULTS

### Latency and Throughput

- **Read Latency:** MongoDB achieved an average of 18 ms vs MySQL's 25 ms, a statistically significant 28% reduction ( $t(8) = 4.12$ ,  $p = 0.003$ ).
- **Write Latency:** MongoDB averaged 22 ms vs MySQL's 30 ms (27% reduction;  $t(8) = 3.87$ ,  $p = 0.005$ ).
- **Throughput:** NoSQL delivered 2200 ops/sec vs SQL's 1500 ops/sec, representing a 47% increase ( $t(8) = 5.45$ ,  $p < 0.001$ ).

### Resource Utilization

- **CPU Utilization:** MongoDB consumed an average of 65% CPU vs MySQL's 55%, an 18% increase. This reflects MongoDB's I/O threading and memory-mapped file usage.
- **Memory Footprint:** MongoDB required 768 MB of RAM vs MySQL's 512 MB, a 50% increase, due to its in-memory working set for indexes and document caching.

### Consistency Observations

- Under strong consistency settings, both databases maintained data integrity. However, MongoDB's "majority" write concern introduced minor latency overhead compared to its default eventual-style configurations, suggesting tunable trade-offs for applications willing to relax consistency.

### Statistical Significance

All measured differences passed the threshold for statistical significance ( $p < 0.01$ ), indicating that observed performance improvements and resource increases are unlikely due to chance.

## CONCLUSION

This study provides a detailed, data-driven comparison of SQL (MySQL 5.7) and NoSQL (MongoDB 4.0) databases as of 2019, targeting representative web application workloads. Key takeaways:

- **Performance:** NoSQL exhibits substantially lower read/write latencies and higher throughput—28% and 27% latency reductions, 47% throughput increase—making it attractive for high-traffic, unstructured data scenarios.
- **Resource Trade-offs:** These benefits incur an 18% rise in CPU utilization and a 50% increase in memory usage, which must be weighed against available infrastructure budgets.
- **Consistency:** While SQL offers strong ACID guarantees out-of-the-box, NoSQL's tunable consistency can approach similar guarantees with minimal performance penalty, offering flexibility for application-specific consistency requirements.

### Engineering Implications:

Application architects should consider NoSQL for session storage, product catalogs, and high-velocity data

ingestion when horizontal scalability and low latency dominate requirements. Conversely, SQL remains preferable for transactional order processing, reporting, and scenarios demanding complex join operations and legacy tool integration. Hybrid architectures leveraging both paradigms can optimize across these dimensions, but rigorous benchmarking—such as the methodology herein—should guide component selection.

### Future Scope:

Subsequent research should explore polyglot persistence best practices, automated workload-driven database tuning, and cost-efficiency analyses across cloud provider pricing models. Additionally, frameworks to more easily benchmark emerging NewSQL systems (e.g., CockroachDB, VoltDB) under similar workloads could further inform data platform strategies.

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