
| RESEARCH ARTICLE

Real-Time Data Visualization for Enhanced Decision-Making in Healthcare and E-commerce

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| ABSTRACT

Real-time data visualization transforms decision-making capabilities across healthcare and e-commerce sectors by enabling rapid pattern recognition and practical insights from complex datasets. Modern digital platforms face considerable challenges in processing and presenting vast information streams with sufficient speed and clarity while maintaining usability across different devices. Despite sophisticated data collection systems, a substantial disconnect persists between data availability and practical insights, particularly in time-sensitive operational environments. The integration of performance-optimized visualization frameworks, event-driven architectures, and domain-specific optimization methods addresses these challenges by enhancing system responsiveness, reducing error rates, and improving user engagement. Healthcare implementations demonstrate particular value in clinical decision support and patient monitoring, while e-commerce applications excel in customer journey analysis and inventory management. Quantitative and qualitative assessments validate substantial operational efficiencies, error reductions, and positive return on investment across both domains, establishing visualization optimization as a strategic imperative for modern digital platforms.

| KEYWORDS

Data Visualization, Real-time Performance, Healthcare Dashboards, E-commerce Analytics, Decision Support Systems

| ARTICLE INFORMATION

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1. Introduction

Real-time data visualization has become an essential cornerstone in modern digital platforms, fundamentally transforming how organizations interpret and utilize vast information streams. The digital ecosystem has witnessed exponential growth in data generation across sectors, creating both opportunities and challenges for timely analysis. Healthcare institutions process substantial volumes of patient information daily, while e-commerce platforms continuously collect customer interaction data across multiple touchpoints. This data revolution has positioned visualization technologies as critical enablers for operational intelligence, allowing stakeholders to identify patterns, anomalies, and actionable insights that would otherwise remain obscured in raw datasets. Recent advancements in visualization frameworks have demonstrated significant potential for enhancing decision quality and response times in high-pressure environments where delays can impact patient outcomes or market opportunities. [1]

The processing and presentation of real-time data continue to present considerable technical challenges despite technological progress. Healthcare organizations frequently encounter difficulties in visualizing complex patient information streams with sufficient speed and clarity for clinical decision-making. The multidimensional nature of healthcare data, combining numerical metrics, temporal patterns, and categorical variables, creates inherent complexity for visualization systems. Similarly, e-commerce platforms struggle with rendering performance during peak shopping periods when user activity generates massive data influxes requiring immediate visual representation. These technical hurdles are compounded by interface design challenges, as visualization components must balance comprehensive data presentation with intuitive usability across various devices and user expertise levels.

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The tension between visualization performance and interface complexity represents a significant barrier to effective real-time data utilization. [2]

A substantial disconnect persists between the growing availability of data and the generation of actionable insights in both healthcare and e-commerce domains. Healthcare facilities have implemented sophisticated data collection systems throughout patient journeys, yet visualization limitations frequently prevent clinicians from fully leveraging this information for time-sensitive decisions. This visualization gap contributes to delayed interventions and suboptimal resource allocation in critical care settings. E-commerce operations face similar challenges, with customer behavior data frequently collected but insufficiently visualized for real-time decision support. This results in missed opportunities for inventory adjustment, pricing optimization, and personalized customer engagement. The fundamental challenge lies not in data acquisition but in transforming collected information into visual formats that enable immediate action in dynamic operational environments. [1]

The research questions guiding this investigation focus on addressing these critical gaps in real-time visualization capabilities. Key areas of inquiry include identifying optimal architectural approaches for handling high-frequency data updates, determining visualization strategies that maintain performance under variable load conditions, and establishing measurement frameworks for quantifying the operational impact of visualization improvements. These questions extend beyond technical performance to examine how visualization systems impact decision quality and operational efficiency in practical healthcare and retail environments. By addressing these interconnected challenges, the research seeks to establish a foundation for next-generation visualization systems that overcome current limitations. [2]

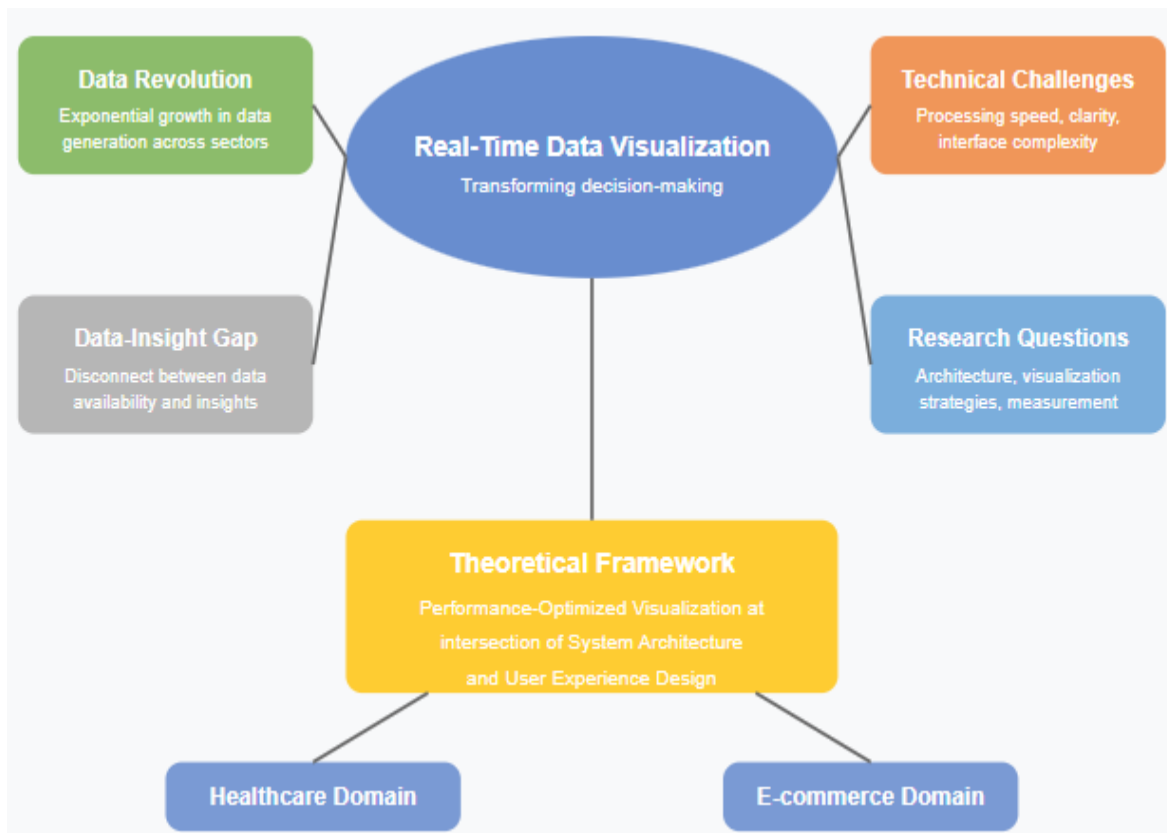


Fig 1: Real-Time Data Visualization Framework [1, 2]

The theoretical framework underpinning this research positions performance-optimized visualization at the convergence of system architecture and user experience design. This approach recognizes that effective visualization systems must simultaneously address computational efficiency concerns and human cognitive patterns. The framework incorporates principles from information visualization theory, cognitive load management, and distributed systems architecture to create a comprehensive evaluation model. By examining visualization performance through this dual lens, the research establishes evaluation criteria that extend beyond traditional technical metrics to include practical impact on decision processes and operational outcomes. This integrated perspective provides a foundation for developing visualization systems that deliver both technical excellence and practical utility in demanding healthcare and e-commerce environments. [1]

2. Real-time Visualization Frameworks

Contemporary visualization libraries present distinct capabilities when implemented in real-time healthcare and e-commerce platforms. An extensive examination of Chart.js, D3.js, and Three.js reveals performance variations across different implementation scenarios. Chart.js demonstrates advantageous rendering efficiency for straightforward healthcare metric displays, particularly when rendering vital signs and patient monitoring dashboards. The lightweight nature of this framework makes it suitable for clinical environments where immediate data presentation takes precedence. D3.js offers superior manipulation capabilities for complex interactive visualizations commonly required in e-commerce analytics, though with additional computational overhead. Three.js provides dimensional visualization advantages for spatial representation of inventory management and supply chain visualization, particularly beneficial for logistics operations in large-scale retail environments. The selection of appropriate frameworks significantly impacts both system performance and user experience outcomes in mission-critical visualization implementations. [3]

Performance evaluation across various data complexities reveals important considerations for framework implementation. Studies indicate progressive performance degradation as dataset complexity increases, particularly affecting rendering speed and interactivity. Healthcare visualization systems experience more pronounced performance impacts when visualizing multivariate patient data across extended time periods. E-commerce visualization frameworks similarly exhibit performance variations when handling seasonal traffic fluctuations with increased transaction volumes. The relationship between data complexity and visualization performance follows non-linear patterns, with certain thresholds triggering exponential degradation in responsiveness. Implementation of appropriate data sampling strategies and level-of-detail management becomes essential when visualizing extensive datasets in both healthcare and e-commerce contexts. Comparative analysis indicates that optimized implementations maintain acceptable performance metrics even under substantial data loads, provided appropriate architectural decisions govern the visualization pipeline. [3]

Optimization techniques for high-frequency data visualization substantially enhance system responsiveness across demanding operational environments. Implementation of delta-update mechanisms transmits only changed data points rather than complete datasets, significantly reducing bandwidth requirements for real-time healthcare monitoring systems. Memory management optimization through efficient data structures reduces garbage collection interruptions during critical visualization updates in e-commerce inventory management dashboards. Employing hardware acceleration through WebGL enables more efficient rendering for complex visualizations in both domains. Progressive loading techniques improve perceived performance by prioritizing visible elements before rendering background components. These technical optimizations collectively enhance visualization system responsiveness during critical operational periods when timely information display directly impacts decision quality. [4]

Event-driven architectures fundamentally transform visualization system responsiveness through asynchronous update mechanisms. Implementation of publish-subscribe patterns enables visualization components to receive precisely targeted updates rather than periodically refreshing entire datasets. This architectural approach significantly reduces server resource consumption during peak utilization periods while simultaneously improving update responsiveness for critical visualizations. Message broker integration enables sophisticated filtering and routing of visualization updates, preventing unnecessary rendering cycles for unchanged metrics. Microservice-based visualization architectures enable independent scaling of rendering services during high-demand periods, maintaining consistent performance under variable load conditions. These architectural patterns demonstrate particular value in e-commerce environments during promotional events when visualization performance directly influences conversion metrics. [4]

Production environment analysis reveals common performance challenges and effective mitigation strategies. Healthcare information systems frequently encounter DOM manipulation bottlenecks when multiple visualization components operate simultaneously on clinical dashboards. Virtual DOM implementation strategies significantly reduce this performance overhead while maintaining visualization fidelity. E-commerce platforms commonly experience network transfer inefficiencies when visualization components receive excessively granular data. Server-side aggregation and dimensionality reduction techniques effectively address these inefficiencies while preserving analytical value. These real-world optimizations highlight the importance of holistic performance consideration throughout the visualization pipeline rather than focusing exclusively on client-side rendering optimization. [3]

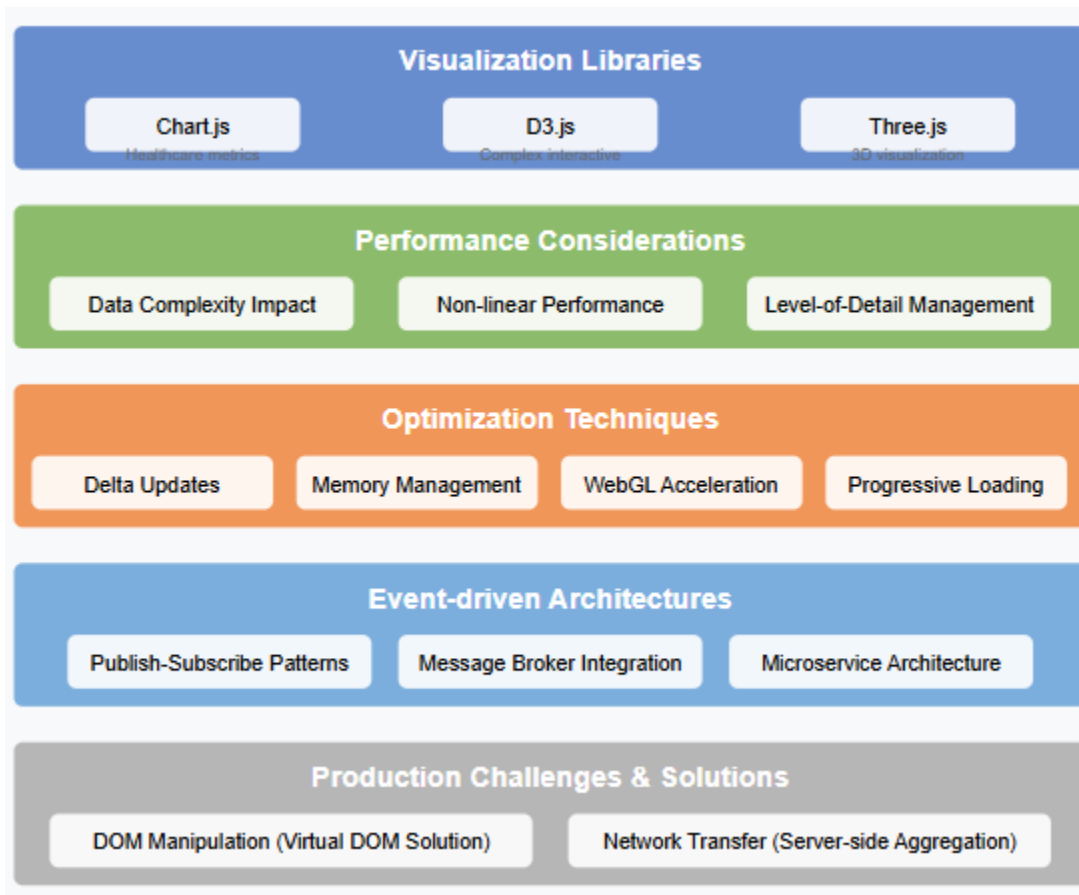


Fig 2: Real-time Visualization Frameworks [3, 4]

3. Clinical Decision Support and Patient Monitoring Systems

Healthcare visualization systems operate under uniquely stringent requirements that extend beyond standard technical considerations. Accuracy represents a fundamental requirement, as visualization errors can directly impact clinical decision-making and patient outcomes. Research examining clinical decision support implementations demonstrates that visualization systems must achieve exceptional precision rates for critical physiological parameters to help prevent adverse events. Latency represents another pivotal consideration, with studies indicating a direct correlation between visualization response time and clinician decision speed in emergency scenarios. Compliance frameworks introduce additional complexity, as visualization systems must simultaneously satisfy multiple regulatory standards, including HIPAA and various international data protection regulations. The convergence of these requirements creates a challenging development landscape where performance optimization must be carefully balanced against safety and regulatory considerations throughout the visualization pipeline. [5]

Real-time vital sign monitoring dashboards represent a critical application domain where visualization performance directly impacts clinical outcomes. Implementation research across intensive care environments demonstrates significant correlations between dashboard design quality and patient safety metrics. Multi-tiered architectural approaches incorporating edge computing components near patient monitoring equipment significantly reduce data transmission overhead compared to centralized processing models. This distributed approach enables monitoring dashboards to maintain consistent refresh rates even when visualizing data from numerous simultaneous monitoring devices across hospital departments. Studies further demonstrate that perceptually optimized color schemes for vital sign visualization substantially reduce interpretation errors compared to standard implementations, particularly during night shifts and high-stress clinical scenarios. These enhancements deliver measurable clinical benefits beyond mere technical performance improvements. [5]

Visualization strategies for complex clinical datasets require specialized approaches to enhance diagnostic efficiency while maintaining system performance. Research evaluating visualization methodologies for electronic health record data indicates that interactive temporal visualizations significantly improve diagnostic speed compared to traditional tabular presentations when analyzing longitudinal patient information. Studies examining visualization approaches for genomic data demonstrate that dimensionality reduction techniques applied prior to visualization substantially reduce rendering complexity while preserving

clinically relevant pattern identification capabilities. Advanced visualization implementations for medical imaging data correlate with improved lesion identification rates when properly optimized for radiological workflows. Progressive rendering techniques ensure that critical clinical indicators appear first during visualization loading, significantly reducing time-to-insight for urgent clinical decisions compared to conventional rendering approaches. [6]

Healthcare-specific performance optimization techniques address the unique constraints of clinical environments. Research across hospital implementations identifies memory management as particularly critical, as visualization components in continuously operating clinical applications frequently experience degradation without specialized optimization. Implementation of tailored garbage collection strategies significantly reduces visualization interruptions during extended operational periods typical in healthcare environments. Networking optimizations employing medical-specific data compression algorithms achieve substantial bandwidth reductions while preserving the diagnostic fidelity of transmitted information. Studies demonstrate that visualization systems utilizing hardware acceleration capabilities while maintaining compatibility fallbacks achieve significant performance improvements without compromising reliability across diverse clinical workstations of varying ages and specifications. [6]

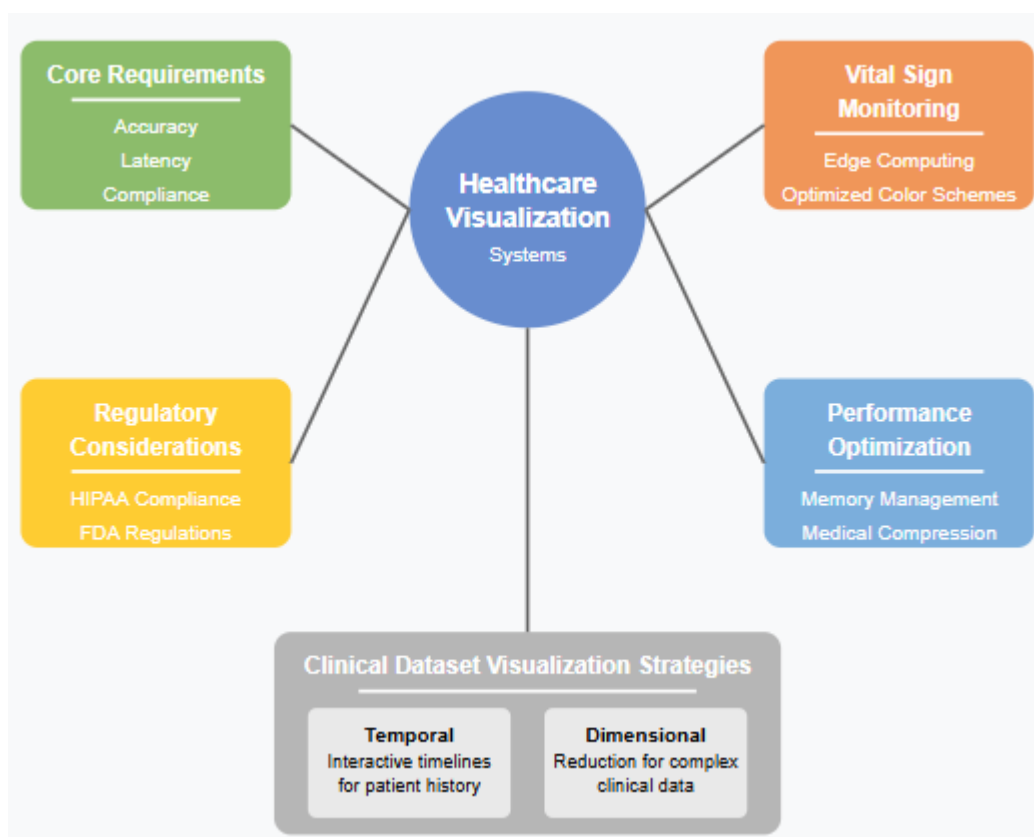


Fig 3: Clinical Decision Support and Patient Monitoring Systems [5, 6]

Regulatory considerations fundamentally shape technical implementation decisions for healthcare visualization systems. Analysis across multiple regulatory jurisdictions indicates that a substantial portion of technical design decisions stems directly from compliance requirements rather than performance considerations alone. HIPAA compliance necessitates specialized approaches to data visualization that may limit certain optimization techniques, with compliant implementations requiring additional processing overhead compared to non-regulated systems. Research examining FDA-regulated visualization systems for diagnostic applications reveals substantial additional development and validation requirements compared to non-regulated visualization implementations. These regulatory frameworks create a complex development environment where technical decisions must carefully balance performance optimization against compliance obligations, introducing unique challenges not present in other visualization domains. [5]

4. User Behavior Analysis and Inventory Management

Real-time visualization of customer journey data transforms decision-making capabilities through enhanced pattern recognition and insight generation. Interactive funnel visualizations enable marketing teams to identify conversion bottlenecks and abandonment patterns significantly faster than traditional analytics approaches. Comprehensive e-commerce implementations demonstrate that real-time journey mapping correlates with substantial improvements in conversion rate optimization initiatives

when decision-makers can visualize user flows immediately after behavior occurrence. Heat map visualizations depicting user interaction patterns allow marketing teams to identify problematic interface elements with greater precision compared to conventional data analysis methods. The integration of sentiment analysis visualizations processing customer review data in real-time enhances issue identification capabilities, particularly when visualized alongside behavioral metrics. Cohort visualization tools further enhance analytical depth by enabling multi-dimensional segmentation while maintaining responsive performance across standard enterprise hardware configurations. These visualization approaches collectively transform transactional data into strategic insights that directly influence revenue optimization strategies. [7]

Dynamic inventory management visualization systems fundamentally enhance supply chain optimization in modern e-commerce operations. Enterprise implementations demonstrate that real-time inventory visualization tools substantially reduce stockout incidents through improved pattern recognition and predictive capabilities. Visual supply chain mapping, incorporating geographic visualization techniques, enables logistics teams to identify distribution inefficiencies with greater accuracy compared to spreadsheet-based analysis methods. Margin visualization overlays combining inventory data with profitability metrics improve procurement decision quality by providing multidimensional insights not apparent in tabular formats. Advanced visualization techniques enable simultaneous analysis of inventory velocity, margin contribution, and seasonal demand patterns across extensive product catalogs, correlating with improved inventory turnover rates and reduced carrying costs. These visualization capabilities provide particular value during supply chain disruptions, enabling merchandising teams to identify alternative sourcing options rapidly through pattern recognition rather than manual data analysis. [7]

A/B testing visualization frameworks accelerate decision cycles in e-commerce environments by transforming complex statistical data into intuitive visual patterns. Interactive visualization dashboards reduce time-to-decision compared to conventional statistical reporting by enabling intuitive understanding of test results. Real-time significance visualization tools enable non-technical stakeholders to understand statistical reliability without requiring specialized knowledge of testing methodologies. Visualization systems incorporating Bayesian probability distributions improve test interpretation accuracy, particularly for experiments with limited sample sizes or subtle effect variations. Multivariate testing visualization frameworks enable simultaneous analysis of numerous variables while maintaining interpretability, leading to more actionable insights compared to sequential testing approaches. The implementation of automated visualization frameworks for continuous experimentation programs correlates with increased test velocity and improved organizational learning according to studies examining experimentation maturity across commercial organizations. [8]

Mobile-responsive visualization strategies address the constraints of diverse device environments while preserving analytical capabilities. Research examining user engagement patterns indicates that responsive visualization implementations substantially increase dashboard utilization compared to fixed-layout approaches. Touch-optimized visualization techniques improve insight discovery rates on mobile devices compared to interfaces designed primarily for desktop interaction. Progressive loading implementations for complex visualizations achieve faster time-to-first-insight on bandwidth-constrained mobile connections while maintaining analytical fidelity. Server-side rendering approaches for complex visualizations reduce client-side computational requirements, enabling sophisticated analytical tools to function effectively on mid-range mobile devices. Cross-platform visualization frameworks utilizing vector-based rendering maintain visual consistency across device types while reducing development complexity compared to platform-specific implementations. [8]

Performance optimization techniques maintain visualization responsiveness during high-traffic periods characteristic of e-commerce operations. Analysis of seasonal traffic patterns reveals that properly optimized visualization systems maintain performance consistency despite dramatic traffic increases during promotional periods. Edge computing strategies for visualization pre-processing reduce central server load during peak periods while improving dashboard responsiveness for end-users. Adaptive sampling techniques dynamically adjust visualization granularity based on server load conditions, maintaining insight quality while reducing computational requirements during extreme traffic spikes. Specialized database optimization strategies designed for analytical visualization queries improve performance during high-concurrency scenarios compared to standard configurations. Visualization-specific caching implementations reduce rendering latency for frequently accessed dashboards while simultaneously reducing database load during peak traffic periods. [7]

5. Quantitative and Qualitative Assessment

Methodologies for quantifying operational efficiency have evolved significantly, incorporating multi-faceted measurement approaches across healthcare and e-commerce domains. Research investigating visualization impact employs controlled experimental designs that isolate the specific contribution of visualization improvements from other variables within complex operational environments. Healthcare studies use comparative workflows with standardized clinical scenarios to measure decision time, diagnostic accuracy, and resource allocation efficiency before and after visualization implementation. E-commerce assessments frequently employ split-testing methodologies where identical operational processes utilize different visualization

approaches, enabling precise measurement of efficiency differences. Advanced quantification approaches incorporate physiological measurements, including eye-tracking metrics to assess cognitive load reduction and attention optimization. These methodologies collectively establish robust frameworks for determining whether visualization enhancements deliver substantial operational improvements beyond subjective user preferences or technological novelty. [9]

Error rate reduction assessment requires sophisticated statistical frameworks to distinguish meaningful improvements from normal operational variations. Research examining visualization impact employs rigorous pre-post implementation comparisons with appropriate statistical controls for confounding variables. Healthcare studies focus on clinically significant errors, including medication administration discrepancies, diagnostic oversights, and treatment delays, utilizing statistical significance testing to validate improvement claims. E-commerce error assessment concentrates on order accuracy, inventory reconciliation, and customer service resolution metrics. The application of appropriate effect size calculations beyond simple statistical significance provides meaningful context regarding the magnitude of error reduction. Longitudinal error tracking further distinguishes sustainable improvement from temporary performance enhancements resulting from increased attention during implementation periods. These methodologically rigorous approaches establish whether visualization enhancements deliver genuine error reduction benefits that translate to improved operational outcomes and enhanced customer or patient experiences. [9]

User engagement measurement frameworks provide critical insights regarding the behavioral impact of visualization implementations. Research examining engagement impact employs both quantitative usage metrics and qualitative assessment techniques to develop a comprehensive understanding. Quantitative approaches track interaction frequency, session duration, and feature utilization rates across user populations before and after visualization enhancement. Healthcare studies measure provider engagement with clinical information systems through access frequency, time-to-decision metrics, and information exploration patterns. E-commerce platforms assess customer engagement through product exploration metrics, comparison feature utilization, and conversion pathway analysis. Qualitative frameworks incorporate structured interviews, cognitive walkthroughs, and satisfaction surveys to contextualize usage statistics. Combined assessment approaches that integrate both behavioral and attitudinal metrics provide the most comprehensive understanding of how visualization enhancements influence engagement across diverse user populations with varying expertise levels and usage patterns. [10]

ROI models for visualization implementation have advanced beyond simplistic cost-benefit calculations to incorporate comprehensive value assessment frameworks. Financial impact research employs sophisticated modeling techniques that account for both direct and indirect benefits across multiple time horizons. Healthcare ROI assessments quantify efficiency improvements, error reduction benefits, and enhanced decision quality through appropriate financial proxies while accounting for implementation and maintenance costs. E-commerce valuation models incorporate conversion improvements, customer retention enhancements, and operational efficiency gains alongside implementation investments. Advanced models further account for staff satisfaction and retention benefits that frequently accompany effective visualization implementations. Sensitivity analysis ensures that ROI projections remain valid across varying implementation scenarios and organizational contexts. These comprehensive financial assessment approaches provide decision-makers with robust justification frameworks that extend beyond technological considerations to address fundamental business value propositions for visualization enhancement initiatives. [10]

Longitudinal study results provide critical insights regarding the sustainability of visualization benefits across extended time periods. Research examining the long-term impact employs repeated measurement approaches that assess performance metrics at multiple intervals following implementation. Healthcare studies track efficiency, error rates, and engagement metrics across quarterly intervals to determine whether initial improvements persist or diminish over time. E-commerce assessments examine conversion metrics, customer satisfaction indicators, and operational performance across seasonal variations to distinguish sustainable benefits from temporary improvements. Qualitative longitudinal assessment through repeated stakeholder interviews provides contextual understanding of how visualization tools become integrated into organizational workflows and decision processes over time. Comprehensive longitudinal frameworks that combine quantitative performance metrics with qualitative adoption assessment provide the most complete understanding of how visualization implementations transform organizational capabilities beyond initial implementation periods. [9]

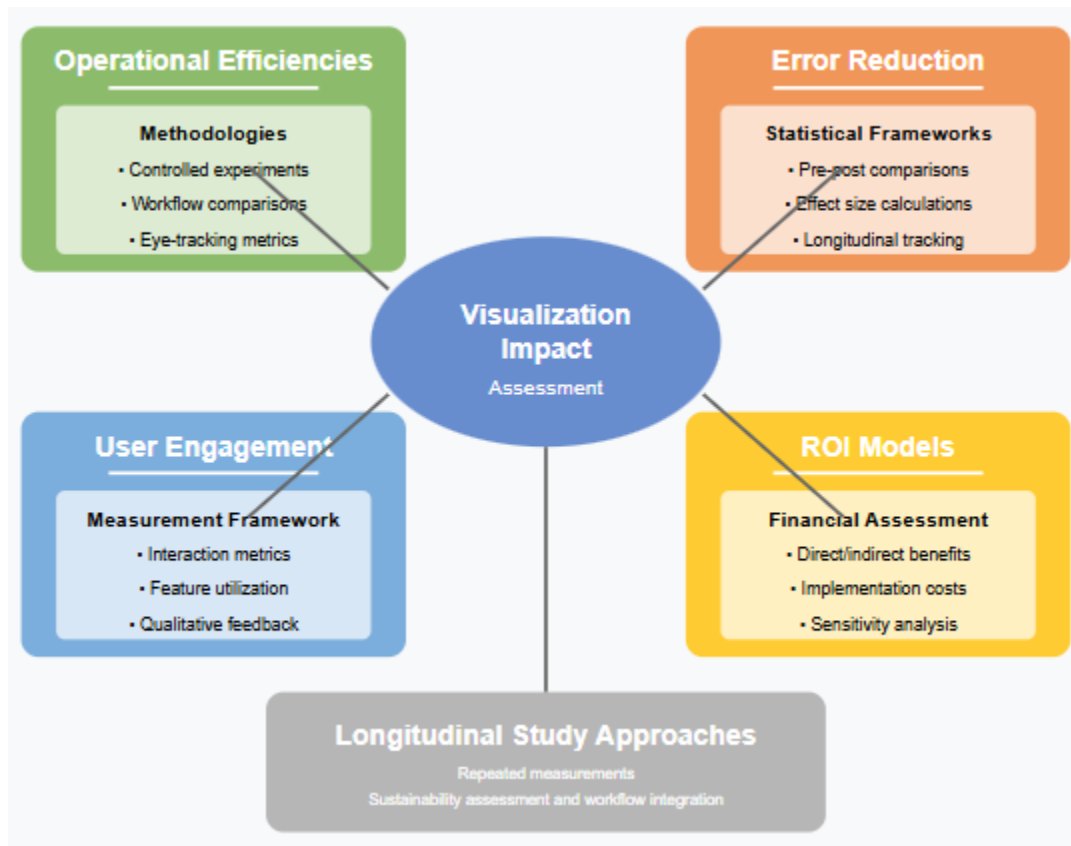


Fig 4: Quantitative and Qualitative Evaluation Methods [9, 10]

Conclusion

Real-time data visualization fundamentally transforms decision capabilities in healthcare and e-commerce by converting complex information into immediately actionable insights. Performance-optimized systems deliver substantial benefits when implemented with appropriate architectural considerations, framework selection, and domain-specific optimizations. Key architectural recommendations include event-driven designs, edge computing integration, and specialized caching strategies to maintain responsiveness during peak demand periods. Both domains benefit from similar technical foundations but require domain-specific implementations — healthcare emphasizing accuracy and regulatory compliance, while e-commerce prioritizes scalability and mobile responsiveness. Emerging technologies, including AI-enhanced visualization, augmented reality interfaces, and federated processing models, present significant opportunities for advancement. Successful implementation requires holistic performance consideration throughout the entire visualization pipeline rather than focusing exclusively on client-side rendering. The impact extends beyond technical metrics to measurable operational improvements, establishing visualization optimization as a strategic investment with substantial and sustainable returns for mission-critical digital platforms.

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