

QUANTUM MARKETING AND REAL-TIME PERSONALIZATION: A CONCEPTUAL REVIEW

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Abstract

The emergence of quantum computing is prompting renewed discussion on the future of marketing strategy, particularly around real-time personalization and customer engagement. This paper presents a conceptual analysis of Quantum Marketing and its potential implications for business strategy, based on a review of existing literature and documented case discussions in academic and industry sources. Using a qualitative document analysis method, the study examined peer-reviewed articles, industry reports, and conference proceedings published between 2020 and 2025. The analysis focused on identifying recurring themes related to opportunities, technical requirements, and implementation challenges associated with applying quantum computing concepts to marketing functions. The review highlights that discussions on quantum marketing emphasize potential advantages in data processing speed and personalization capabilities, alongside significant barriers including technical complexity, data infrastructure needs, and limited accessibility. The paper concludes that while quantum computing remains largely experimental in marketing contexts, its development warrants ongoing conceptual and practical attention. It recommends that future empirical studies test these propositions and those firms interested in the area prioritize foundational investments in data architecture and digital readiness.

Keywords: Quantum Marketing, Real-Time Personalization, Quantum Computing, Customer Engagement, Digital Transformation

Introduction

The evolution of marketing practice has been closely tied to advances in data processing and analytics. Current real-time personalization relies on classical computing systems and artificial intelligence (AI) and machine learning (ML) algorithms. These systems analyze historical and streaming customer data to segment audiences, predict preferences, and automate content delivery at scale (Luu *et al.*, 2024; Patil, 2025). AI-driven tools have become standard in marketing strategy for improving customer engagement and targeting efficiency. Distinct from these operational systems, quantum computing represents a separate computational paradigm based on principles of superposition and entanglement. In marketing literature, Quantum Marketing is the conceptual application of quantum algorithms to problems such as high-dimensional optimization, pattern recognition, and complex data synthesis (Amin, 2024). It is important to distinguish between current AI/ML applications, which are implemented in industry practice, and quantum-based approaches, which remain at the stage of theoretical modeling and early experimental exploration.

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This paper examines Quantum Marketing as a conceptual domain within marketing research. Using a review of peer-reviewed literature and industry reports, the study maps proposed mechanisms through which quantum computing could extend existing personalization frameworks, identifies recurring themes in conceptual discussions, and considers the conditions under which such approaches might complement current AI/ML methods. The analysis focuses on the conceptual and strategic implications for marketing practice, without attributing current deployment of quantum systems to specific firms. To support future conceptual and empirical work, scholars emphasize the need for robust data infrastructures and data governance practices as prerequisites for any advanced computational application in marketing (Rini *et al.*, 2024; Sarioguz & Miser, 2024). The study also highlights that realizing potential benefits depends on addressing challenges related to data privacy, security, and system integration (Gungunawat *et al.*, 2024).

By clarifying the boundary between established AI-driven personalization and hypothetical quantum applications, the paper provides a structured overview for researchers and practitioners tracking the development of advanced computational methods in marketing (Islam *et al.*, 2024). The discussion centers on potential pathways for future integration, data infrastructure considerations, and areas requiring further empirical validation, without overstating current industry adoption.

Statement of the Problem

The advancement of Quantum Marketing for real-time personalization is constrained by challenges that can be organized into technological, organizational, and environmental dimensions. The technological dimension: Quantum Marketing depends on processing high-dimensional and streaming customer data using emerging computational models. This creates issues with data quality and algorithmic transparency. Ensuring data accuracy and relevance remains a challenge when integrating multiple sources for real-time personalization (Kedi *et al.*, 2024). The use of AI and machine learning within these frameworks also raises concerns about algorithmic bias and fairness (Luu *et al.*, 2024). Additionally, the complexity of quantum and hybrid algorithms can reduce explainability, making it difficult to interpret and justify marketing decisions (Islam *et al.*, 2024).

Organizational dimension: Adopting Quantum Marketing requires firms to align internal capabilities with new technological demands. A key barrier is the limited availability of professionals with combined expertise in marketing analytics and quantum computing concepts, which restricts

implementation capacity (Patil, 2025). Organizations also face difficulties integrating novel computational approaches with existing marketing infrastructure, customer data platforms, and decision-making processes. These changes often require adjustments in workflows, data governance, and talent development strategies.

Environmental dimension: External factors further shape the feasibility of Quantum Marketing. Data privacy and security concerns intensify as firms collect and process sensitive customer information, requiring compliance with evolving data protection regulations (Sarioguz & Miser, 2024). The regulatory landscape for both data protection and emerging computing technologies remains in flux, creating uncertainty for strategic planning (Gungunawat *et al.*, 2024). The absence of established industry standards for interoperability between quantum and classical systems also constrains broader adoption and collaboration across firms (Amin, 2024).

Research Questions

1. What potential mechanisms link quantum computing concepts to real-time personalization in marketing?
2. What strategies and enabling conditions are discussed in the literature for integrating quantum computing concepts into marketing practice?
3. How is the relationship between quantum computing applications and marketing performance conceptualized in existing literature?

Objectives of the Study

The broad objective of this study is to critically analyze the conceptual foundations of quantum marketing and its proposed role in real-time personalization. While the specific objectives are as follows:

1. To examine how quantum computing concepts are conceptualized in relation to real-time personalization within existing literature.
2. To identify strategies and enabling conditions discussed for integrating quantum computing concepts into marketing practice.
3. To conceptually evaluate how the relationship between quantum computing applications and marketing performance is framed in the literature.

Theoretical Propositions

The following propositions summarize recurring claims in the literature and guide the analysis:

1. Quantum computing concepts are proposed to enable more granular processing of high-dimensional customer data, which may support more precise real-time personalization compared to classical approaches.
2. The integration of quantum computing into marketing practice is contingent on organizational capabilities including data infrastructure, cross-disciplinary expertise, and alignment between technical and marketing functions.
3. Quantum marketing conceptualizes potential links between advanced computational capabilities and marketing performance.

From Classical Personalization to Quantum: A Computational Perspective

Traditional personalization relies on classical computing methods where data processing scales polynomially with input size. Techniques like collaborative filtering, logistic regression, and decision trees use demographic, transactional, and behavioral data to segment customers and predict preferences (Luu *et al.*, 2024). These methods face practical limits in real-time contexts: as data volume and dimensionality increase, latency rises due to the time complexity of classical algorithms, typically $O(n)$ to $O(n^2)$ for similarity computations (Kedi *et al.*, 2024). Quantum computing introduces a different computational model based on superposition and entanglement. In theory, algorithms such as Grover's search offer quadratic speedup for unstructured search problems $O(\sqrt{N})$, while Quantum Amplitude Estimation can accelerate Monte Carlo methods used in risk and preference modeling (Nielsen & Chuang, 2010). Variational Quantum Eigensolver and Quantum Approximate Optimization Algorithm are also proposed for optimization tasks relevant to resource allocation and ad placement (Farhi *et al.*, 2014).

However, these advantages are conditional. Quantum speedup applies only to specific problem structures, requires error-corrected qubits not yet widely available, and assumes data is efficiently encoded into quantum states - a non-trivial step known as the "input problem" (Aaronson, 2015). This contrasts with the over-promotional tone in some literature that treats quantum computing as a drop-in replacement for classical systems. Classical personalization treated users as predictable, independent agents whose preferences could be captured in fixed feature vectors and modeled with

rules, demographic segments, and statistical methods like collaborative filtering and logistic regression (Lehmann, Netzer & Toubia, 2015). The conceptual model assumed rational decision-making and linear scalability, where content was matched to pre-defined segments based on attributes such as age, location, and purchase history. This approach worked for batch recommendations and email targeting but faltered when faced with high-dimensional data, cold-start scenarios, and the need for immediate adaptation to shifting user context.

The limitation lies in the classical assumption that all relevant attributes can be measured simultaneously and that user intent remains stable between interactions. As digital environments grew more complex, personalization systems began to lag behind real-time expectations of users who interact across multiple channels and generate unstructured behavioral data at high velocity. The conceptual gap became clear: classical models optimize for average behavior, not for the fluid, context-dependent nature of individual choice (Sáez-Ortuño *et al.*, 2024). Quantum computing introduces a different conceptual frame by drawing on superposition, entanglement, and uncertainty from quantum physics (University of Portsmouth, 2024). Superposition allows a user to hold multiple, even contradictory, preferences until a measurement occurs, reflecting how real consumers may consider premium and budget options simultaneously. Entanglement models the influence of social and contextual factors on decisions, while uncertainty acknowledges that complete knowledge of user state is unattainable in practice. This reframes personalization from deterministic prediction to probabilistic amplitude estimation in a high-dimensional Hilbert space.

Conceptually, this shift moves from “predicting the most likely action” to “maintaining a state of potential actions” that collapses only when context demands it. Instead of static profiles, quantum models represent users as evolving states that can interfere constructively or destructively depending on context, mirroring findings in quantum cognition that human decision-making often violates classical probability rules (University of Portsmouth, 2024). The implication is a system that can reason about ambiguity and context without forcing premature commitment to a single preference profile. In practice, this conceptual perspective is being explored through quantum machine learning algorithms applied to recommendation and segmentation. Quantum kernel methods embed classical data into quantum feature spaces, enabling support vector machines to achieve competitive accuracy on consumer classification tasks with fewer classical resources (Wu, Li & Chen, 2024). Variational

quantum recommendation systems combine classical matrix factorization with quantum sampling to reduce online inference time, prioritizing speed for real-time use cases (Maldonado-Romo *et al.*, 2025). The conceptual payoff is a model of personalization that aligns more closely with how people actually make choices: fluid, context-sensitive, and influenced by hidden variables. While hardware constraints keep most applications in the hybrid classical-quantum regime, the conceptual framework provides a roadmap for moving beyond linear scalability limits and toward systems that can maintain and act on multiple potential user states simultaneously (Moran, 2025).

The shift to AI-Driven Real-Time Personalization

AI-driven real-time personalization emerged as deep learning and streaming data infrastructure made it feasible to update user models continuously rather than in nightly batches. Generative AI and large language models enabled systems to produce tailored content, product recommendations, and offers based on individual behaviors as they unfold across web, mobile, and in-app channels (Cognizant, 2024). This marked a shift from static segmentation to dynamic inference, where the system's understanding of a user evolves with every click, scroll, and dwell time. The conceptual change was from "who is this user" to "what is this user doing right now and what are they likely to do next." Customer Data Platforms began integrating agentic AI architectures that reason, adapt, and execute actions across channels without human intervention. By 2025, 50% of agentic AI adopters had already incorporated quantum computing into their digital roadmaps, signaling that real-time AI was creating demand for computational models beyond classical limits (SAS, 2025).

Real-time personalization depends on reducing latency in data ingestion, feature computation, and model inference. Classical systems face combinatorial explosion as the number of variables grows, making it difficult to evaluate all possible actions and contexts within milliseconds. This bottleneck becomes acute in omnichannel environments where pricing, inventory, and messaging must be synchronized instantly across touchpoints (Moran, 2024). AI systems responded by moving toward approximate methods, approximate nearest neighbor search, and streaming gradient updates. However, these are still bounded by classical probability and polynomial-time computation. The conceptual model remains one of incremental improvement within a fixed computational paradigm, even as the data and decision space grow exponentially (Sáez-Ortuño *et al.*, 2024). The business

impact has been measurable: hyper-personalization at scale is now a priority for 67% of life sciences marketers and 69% of insurance leaders focus on real-time customer journey simulation (SAS, 2025). The driver is not just better conversion rates but the expectation that experiences should adapt instantly to context, location, and intent.

Conceptually, this created a tension between the desire for fine-grained, individual-level adaptation and the practical limits of classical computation. Marketing teams began to see real-time personalization as an AI problem, but the underlying compute layer was still classical, creating a ceiling on how many variables and scenarios could be evaluated per interaction (CMWIRE, 2024). This is why quantum computing is entering the conversation now. Agentic AI adopters are more ambitious: 31% expect quantum to impact marketing within two years, and 6% say it's already happening (SAS, 2025). The conceptual link is that agentic systems require complex optimization, simulation, and learning that scale poorly on classical hardware. The shift to AI-driven real-time personalization has therefore set the stage for a conceptual break. It has redefined user expectations and business KPIs around immediacy and granularity, but it has also exposed the limits of classical computation. The next step is not just faster AI, but a different computational model that can handle the combinatorial complexity inherent in true real-time, individual-level decisioning (Moran, 2025).

Quantum Computing as a Conceptual Break

Quantum computing breaks with classical computation by using qubits that exist in superposition, allowing a system to represent multiple states simultaneously rather than a single 0 or 1 (University of Portsmouth, 2024). For personalization, this means a model can maintain multiple potential user intents in parallel and evaluate their interference effects without enumerating every combination classically. The conceptual break is from sequential evaluation to parallel exploration of possibility spaces. This capability is relevant to marketing because audience segmentation, behavior prediction, and optimization are fundamentally combinatorial problems. Quantum computers can process large datasets to refine audience segments with more variables and attributes, enabling faster and more precise refinement (CMWIRE, 2024). The conceptual shift is from coarse segments to microsegments defined by high-dimensional feature interactions that would be infeasible to compute classically in real time.

Customer behavior prediction benefits similarly. Quantum-enhanced machine learning models can deliver deeper insights into preferences, trends, and patterns by processing complex datasets faster. Conceptually, this moves personalization from reactive inference based on historical averages to proactive inference that can incorporate low-probability but high-impact signals buried in high-dimensional data (University of Portsmouth, 2024). Optimization is another area where the conceptual break matters. Marketing optimization involves evaluating countless combinations of budget allocation, channel mix, and audience targeting under constraints. Quantum algorithms can accelerate this process, enabling near real-time testing and feedback analysis for pricing models and campaign adjustments (CMWIRE, 2024). The conceptual model becomes one of continuous optimization rather than periodic batch runs.

Quantum cognition provides a theoretical bridge between quantum mechanics and human decision-making. Research combining quantum cognition theory with graph neural networks has produced models like QUARK that outperform state-of-the-art recommenders by modeling user thoughts as quantum states (Han *et al.*, 2024). This suggests that quantum models may capture aspects of human choice that violate classical probability, such as order effects and context dependence. The conceptual break also extends to simulation. Quantum AI can simulate complex customer journeys across multiple touchpoints, allowing marketers to anticipate outcomes and tailor experiences proactively (SAS, 2025). Instead of relying on historical funnels, systems can run quantum simulations of potential futures and adjust interventions in real time.

However, the conceptual break is constrained by the NISQ era. Current devices are noisy and limited in qubit count, meaning most practical systems use hybrid pipelines where quantum components handle specific subroutines like feature selection or QUBO solving (Alavi *et al.*, 2025). The conceptual model is therefore one of augmentation rather than replacement, with quantum processing offloading the hardest combinatorial subproblems. Looking forward, the conceptual break implies a new design pattern for personalization systems: classical layers handle data ingestion, feature encoding, and delivery, while quantum layers handle optimization, sampling, and state estimation. As hardware matures, the conceptual boundary will shift from “quantum-inspired” heuristics to genuinely quantum-native models that treat user intent as a quantum state (Moran, 2025).

Current State of Quantum Marketing Claims

The current state of quantum marketing claims is a mix of strategic roadmap planning and early experimentation, with few production deployments. A 2025 SAS survey found that 50% of agentic AI adopters have already incorporated quantum computing into their innovation roadmaps, and 31% expect it to impact marketing within two years (SAS, 2025). This indicates that claims are moving from speculative to planning stages, driven by the computational demands of agentic AI. Most public claims focus on potential rather than deployed systems. Industry reports highlight applications in audience segmentation, behavior prediction, and real-time optimization, noting that quantum can process large datasets to refine segments with more precision and speed (CMWIRE, 2024). Vendors and consultancies promote quantum-enhanced personalization, but these are typically pilot projects or simulations rather than at-scale production systems.

The investment landscape supports this cautious optimism. In 2024, private and public investors poured nearly \$2.0 billion into quantum technology startups, a 50% increase from 2023 (McKinsey, 2025). Quantum computing companies generated \$650-750 million in revenue in 2024 and are expected to surpass \$1 billion in 2025, largely from hardware deployment in private industry and defense. However, the bulk of revenue still comes from hardware and consulting, not from marketing applications (McKinsey, 2025). A key challenge is distinguishing credible claims from hype. Due-diligence guides warn against startups that present consulting or workshops as product revenue, and against roadmaps promising 1000 qubits in 2025 and full fault tolerance by 2026 without intermediate milestones (Post Quantum, 2025). The consensus is that commercial quantum advantage for marketing remains 3-7 years out, with near-term value in hybrid algorithms running on simulators or small quantum processors.

Academic research is advancing on specific subproblems. Quantum semi-random forests for recommender systems achieve performance comparable to classical baselines using only five qubits by combining SVD sketching, QAOA feature selection, and quantum forests (Alavi *et al.*, 2025). Variational quantum recommendation systems show that a small number of online circuit executions can yield moderately accurate predictions, highlighting a trade-off between inference time and accuracy (Maldonado-Romo *et al.*, 2025). From an industry perspective, the value capture is expected to shift toward application-layer enterprises that integrate quantum into high-impact workflows. By

2030, finance, transportation, and life sciences are projected to account for nearly 80% of quantum-derived economic impact, with machine learning and optimization contributing 33% and 22% respectively (McKinsey, 2025). Marketing is not yet a leading vertical in these models, but customer journey simulation and hyper-personalization are cited as emerging use cases (SAS, 2025).

The current state also includes a growing emphasis on abstraction layers and orchestration. Reports call for better bridging between qubit physics and business problems, and for unified orchestration that lets quantum and classical HPC resources operate seamlessly (World Economic Forum & Accenture, 2025). This reflects a maturation from “quantum for quantum’s sake” to integration into existing martech stacks. In summary, quantum marketing claims in 2025 are credible at the level of research, pilots, and strategic planning, but not yet at the level of widespread production deployment. The claims are grounded in real algorithmic advances and investment momentum, but they are constrained by hardware limitations and the need for hybrid architectures. The next 2-3 years will likely determine whether these claims translate into measurable business impact in personalization and optimization (Moran, 2025).

Critical synthesis of the literature reveals significant constraints that are often underemphasized:

Computational constraints: Current noisy intermediate-scale quantum (NISQ) devices have limited qubits, high error rates, and short coherence times. They are not yet suitable for processing the volume of data used in commercial personalization at scale (Preskill, 2018). Most practical implementations remain simulations or hybrid approaches where only subroutines run on quantum hardware.

Data and integration constraints: Quantum algorithms require data to be encoded into quantum states. Efficient encoding for large, heterogeneous marketing datasets remains an open research problem. Integrating quantum modules with existing martech stacks also raises compatibility and latency issues (Patil, 2025).

Counter-arguments and skepticism: Multiple authors caution against overestimation of near-term impact. Aaronson (2015) notes that quantum advantage is problem-specific and not universal. In marketing, where data is noisy and outcomes are probabilistic, the incremental benefit of quantum methods over optimized classical baselines is unclear. Some studies report no statistically significant

improvement over classical algorithms for recommendation tasks on current hardware (Havlíček *et al.*, 2019).

Research Gap/Gap in Literature

Beyond technical limits, the literature highlights governance concerns. Processing sensitive customer data with novel computational models raises questions about explainability, auditability, and compliance with data protection regulations (Sarioguz & Miser, 2024). The lack of standardized benchmarks for quantum marketing applications makes cross-study comparison difficult (Amin, 2024). A critical gap is the absence of empirical studies on real-world deployments. Most claims about performance gains remain theoretical or based on simulations. This limits the ability to assess ROI, scalability, or practical value compared to classical alternatives. Despite the growing interest in quantum marketing and real-time personalization, a notable gap exists in the literature regarding the practical implementation of quantum computing in marketing strategies. While studies highlight the potential benefits of quantum computing in enhancing personalization (Amin, 2024; Greene, 2026), there is a lack of research on the specific challenges businesses face when integrating quantum technologies into existing marketing frameworks. Most discussions remain theoretical, focusing on the transformative potential of quantum computing rather than actionable implementation roadmaps.

Furthermore, existing literature often overlooks the intersection of quantum marketing and data privacy concerns. As quantum computing enables more sophisticated data analysis, the implications for data protection and customer privacy are significant (Sarioguz & Miser, 2024). There is limited research exploring how businesses can balance the benefits of quantum-driven personalization with growing demands for data security and regulatory compliance. The literature also lacks empirical studies on the long-term impact of quantum marketing on customer behavior and business outcomes. While early adopters like Amazon and Netflix demonstrate success with real-time personalization (Rini *et al.*, 2024), more research is needed to understand the scalability and sustainability of quantum marketing strategies across industries. Addressing these gaps can provide businesses with clearer guidance on leveraging quantum computing for effective and responsible marketing.

Synthesis and Direction for Conceptual Review

Synthesizing across studies shows a pattern: technical papers emphasize algorithmic potential, while business-oriented papers overstate readiness. A balanced view requires distinguishing between:

1. Theoretical complexity gains_ proven in computational complexity theory,
2. Demonstrated performance_ on small-scale problems, and
3. Operational feasibility in marketing contexts.

Future conceptual work should focus on mapping where quantum algorithms plausibly outperform classical methods, identifying problem classes in marketing that match those conditions, and articulating the assumptions required for such gains.

Technology-Organization-Environment (TOE) framework

Technology-Organization-Environment (TOE) framework developed by Tornatzky and Fleischer in 1990, is widely used to understand the adoption and implementation of technologies in organizations (Baker, 2011). In the context of Quantum Marketing and Real-Time Personalization, the TOE framework can help analyze how technological factors (like quantum computing capabilities), organizational factors (such as marketing structure and talent), and environmental factors (including regulatory pressures and market trends) influence the adoption of quantum marketing strategies. The TOE framework also underscores the role of external pressures, such as data protection regulations and competitive dynamics, in shaping quantum marketing strategies (Sarioguz & Miser, 2024; McKinsey, 2026). By considering these factors, businesses can develop more robust strategies for implementing quantum marketing, balancing technological potential with organizational and environmental realities. Recent studies emphasize the need for businesses to adapt their strategies in light of quantum advancements (Greene, 2026; IBM, 2026).

Methodology

This study employed qualitative content analysis of secondary data. Sources included peer-reviewed journal articles, industry reports, and official publications on quantum marketing and real-time personalization published. A structured search was carried out in Scopus, Web of Science, IEEE Xplore, and Google Scholar for peer-reviewed articles, conference papers, and book chapters published between 2018 and 2025, using Boolean combinations of “quantum computing,” “marketing,” “personalization,” and “real-time analytics.” Titles, abstracts, and full texts were

screened against defined inclusion and exclusion criteria, resulting in 22 sources for analysis. Coding consistency was ensured through peer debriefing, with discrepancies resolved through discussion of theoretical propositions. The analysis is interpretive and conceptual; no quantitative analysis or hypotheses testing was conducted.

Discussion

Proposition 1

Quantum computing concepts are proposed to address the challenge of processing high-dimensional customer data that overwhelms classical marketing systems. Modern marketing generates data across behavioral, contextual, demographic, and psychographic dimensions, but classical algorithms often reduce this dimensionality to remain computationally tractable. That reduction risks discarding subtle signals that drive individual-level personalization. Quantum computing uses qubits and superposition to represent multiple states simultaneously, providing a theoretical route to retain more granularity in analysis (University of Portsmouth, 2024). The parallel nature of quantum computation allows evaluation of many combinations of customer attributes at once. Where classical systems test segments sequentially, quantum algorithms can explore multiple segmentation hypotheses in parallel. Industry analysis notes that quantum computing can quickly process large datasets, helping marketers refine audience segments with more precision and speed (Moran, 2025). This capability directly supports the creation of micro-segments that classical methods overlook due to time constraints.

With higher granularity comes the possibility of hyper-personalization at the individual level. Instead of assigning customers to broad cohorts, quantum-enhanced models can incorporate behavioral, contextual, and psychographic variables into real-time decisioning. MarTech analysts note that quantum computing could enable real-time personalization of marketing messages and offers based on a multitude of variables, significantly improving engagement and conversion rates (MarTech, 2024). Real-time personalization also depends on low-latency analysis and decision-making. Quantum computing accelerates testing, feedback analysis, and pricing adjustments, enabling teams to modify strategies immediately based on customer actions. Improved data analysis supports better personalization, campaign targeting, and real-time decision-making based on customer actions (Moran, 2025). Predictive analytics stands to improve as quantum systems handle

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complex, non-linear relationships in data more efficiently. By uncovering deeper patterns in preferences and intent, marketers can move from reactive targeting to proactive personalization. With the ability to analyze complex datasets, quantum computing could enhance predictive analytics and allow more accurate forecasting (MarTech, 2024). Quantum AI extends this by simulating customer journeys across multiple touchpoints. Simulating non-linear paths and interactions helps anticipate outcomes before the customer reaches the next stage, allowing preemptive adjustments to content and offers. Early conceptual work positions this as a way to manage the complexity of omnichannel behavior that classical models simplify away (University of Portsmouth, 2024).

Another advantage lies in handling unstructured and multimodal data. Customer interactions include text, images, video, and audio, which are difficult to integrate in classical pipelines without heavy preprocessing. Quantum algorithms under development aim to process multimodal inputs more efficiently, potentially unifying sentiment from social media, visual engagement data, and voice interactions into a single personalization model (MarTech, 2024). The theoretical gains stem from algorithms like quantum amplitude estimation and quantum principal component analysis, which offer polynomial or exponential speedups for specific data processing tasks. While current hardware limits application to small datasets, these complexity advantages underpin the claim that quantum computing could outperform classical approaches in high-dimensional analytics once hardware matures (Moran, 2025).

Despite the promise, quantum hardware remains fragile and requires extreme conditions to operate. Most marketing applications are conceptual, simulation-based, or limited to small datasets. Experts estimate that Q-Marketing could become practical within five to ten years, meaning current work is largely preparatory (University of Portsmouth, 2024). Strategically, firms that develop quantum-ready data infrastructure early may gain a differentiation advantage. The advantage will not come from owning quantum hardware directly, but from building pipelines, talent, and use cases that can leverage quantum capabilities when they mature. In a competitive environment where personalization drives retention and revenue, even marginal gains in precision can compound over time (Moran, 2025).

Proposition 2

The integration of quantum computing into marketing practice depends heavily on organizational capabilities that extend beyond access to quantum hardware. Clean, well-structured, high-quality data is a prerequisite, yet many marketing organizations still operate in silos with inconsistent schemas and weak governance. Without integrated data infrastructure, quantum systems cannot access the inputs needed for meaningful analysis (World Economic Forum, 2025). A capability gap is evident across industries. There is very little quantum capability embedded in companies today, and a lack of resources to explore and build capability, combined with unclear adoption strategies, represents a major barrier (Soller & Wisby, 2024). CEOs are advised to develop longer-term visions for how quantum will change their industry and integrate it into digital workflows rather than treating it as an isolated experiment. Cross-disciplinary expertise is another constraint. Quantum marketing sits at the intersection of quantum physics, computer science, data engineering, and marketing science. Few individuals have expertise across all domains, so organizations need hybrid teams or partnerships with quantum computing providers to translate business problems into algorithmic specifications (World Economic Forum, 2025).

Alignment between technical and marketing functions determines whether projects deliver value. Misalignment often produces technically impressive models that solve the wrong problem or cannot be operationalized in live campaigns. Successful adoption requires marketing teams to articulate business problems clearly and technical teams to communicate constraints in non-technical terms (Soller & Wisby, 2024). Workforce upskilling is highlighted in recent industry guidance. The World Economic Forum recommends that ICT leaders evaluate quantum readiness, invest in quantum-safe cryptography, and upskill their workforce. For marketing, this means training staff to identify viable use cases and interpret quantum-enhanced outputs without overestimating their certainty (World Economic Forum, 2025). Integration with existing martech stacks presents architectural challenges. Quantum systems will augment, not replace, current personalization engines, CRMs, and campaign platforms. Decisions about data flow, latency, and governance determine whether quantum outputs can be used in real time or only for offline analysis (Moran, 2025).

Governance and ethics become more salient as quantum-enhanced analysis increases the resolution of personal data. Access to highly personal data can affect users' privacy, and responsible

and transparent handling of this information is required to influence people's decisions (University of Portsmouth, 2024). Robust governance frameworks are needed to maintain trust and regulatory compliance. Most firms will access quantum computing through cloud providers like IBM, Google, Amazon, and Microsoft due to hardware costs and expertise requirements. Building effective partnerships and managing vendor relationships becomes a core organizational capability. McKinsey notes that leading technology companies drove the bulk of change in 2024 through breakthroughs in error correction and quantum control solutions (McKinsey, 2025). Pilot projects are the current entry point. Companies across sectors are exploring quantum computing through pilots in logistics optimization, fraud detection, and molecular simulation. For marketing, early pilots focus on optimization problems and audience segmentation rather than full-scale personalization, providing learning without large upfront risk (Soller & Wisby, 2024). Organizational readiness acts as the rate-limiting factor. Even if quantum hardware advances rapidly, firms with strong data infrastructure, cross-functional teams, and clear governance will be positioned to pilot and scale quantum marketing applications faster than competitors. Readiness, not hardware access alone, will determine who captures value first (World Economic Forum, 2025).

Proposition 3

The literature on quantum marketing largely conceptualizes potential links between advanced computational capabilities and marketing performance without providing empirical validation. Articles frame quantum marketing as an extension of Marketing 5.0, where deeper computation enables more precise understanding of customers and more responsive interventions. The discussion focuses on possibilities for content personalization, cybersecurity, and engagement rather than measured outcomes (University of Portsmouth, 2024). Theoretical benefits are frequently cited, including improved predictive accuracy, faster optimization, and more granular segmentation. One speculative study reported that a quantum approach yielded 92% accuracy in market trend prediction compared to 75% for classical computing. However, the study notes that these conclusions are based on speculative case studies and theoretical models, limiting the weight of the claim (Adeyemi *et al.*, 2025). No peer-reviewed studies document large-scale deployment of quantum computing in live marketing systems. The literature remains conceptual, simulation-based, or reliant on small-scale experiments. This gap means claims about performance impact remain untested in production

environments where data volume, latency, and noise differ from lab conditions (Adeyemi *et al.*, 2025). The trajectory mirrors early AI adoption in marketing, where extensive conceptual literature preceded empirical validation. Just as AI required years of infrastructure and data maturation before measurable ROI appeared, quantum marketing may follow a similar path. The difference is that quantum hardware constraints make experimentation slower and more costly (Moran, 2025).

Research on marketing capability and performance shows that effects vary based on mediators like innovation capability and customer relationship quality, and moderators like environmental turbulence and firm size. Similar factors likely apply to quantum marketing but have not been tested empirically. Without this, it is unclear where quantum adds value and where classical methods remain sufficient (Lodish & Janakiraman, 2025). Measurement challenges compound the problem. Attributing marketing performance to quantum computing is complex due to confounding variables, long causal chains, and the difficulty of running controlled experiments with novel technology. Standard marketing metrics may not isolate the specific contribution of quantum-enhanced analytics from other changes in the stack (Lodish & Janakiraman, 2025). Much of the current literature is promotional or speculative, emphasizing potential without addressing failure modes, cost, or implementation barriers. This creates a risk of inflated expectations among practitioners and may lead to misallocation of resources if pilot results are overgeneralized (Adeyemi *et al.*, 2025).

To establish causal links, future research needs longitudinal models, difference-in-differences, and synthetic controls when natural experiments occur. Such designs are currently absent in quantum marketing literature, leaving the field without strong evidence of performance impact (Lodish & Janakiraman, 2025). Until production data is available, detailed case studies of pilot projects will be the primary source of evidence. These studies should report not only outcomes but also implementation challenges, costs, and organizational changes. Transparency about limitations will help separate genuine capability from hype (World Economic Forum, 2025). The research agenda moving forward must test whether quantum-enhanced analytics actually improve metrics like conversion rate, customer lifetime value, and ROI, and under what conditions. Without this empirical grounding, quantum marketing remains a promising but unproven domain, and decisions should be framed as exploratory rather than definitive (Adeyemi *et al.*, 2025).

Findings

- 1. Real-time personalization is limited by classical computational complexity:** Current AI-driven personalization systems struggle with combinatorial explosion when evaluating high-dimensional user data in milliseconds. Classical algorithms can't evaluate all possible actions and contexts for each user in real time, forcing reliance on approximations and pre-segmented groups.
- 2. Quantum computing offers a conceptual shift from prediction to probabilistic state management:** Quantum models use superposition and entanglement to maintain multiple potential user intents simultaneously. This aligns better with observed human decision-making, which often violates classical probability rules.
- 3. Marketers are planning for quantum, not yet deploying it at scale:** 50% of agentic AI adopters have added quantum computing to their innovation roadmaps, and 31% expect it to impact marketing within two years. Current use is limited to pilots, simulations, and strategic planning.
- 4. Quantum machine learning shows promise for specific subproblems:** Hybrid algorithms like quantum semi-random forests and variational quantum recommendation systems achieve accuracy comparable to classical baselines using 5-10 qubits for feature selection and sampling. The advantage is reduced online inference time, critical for real-time use cases.
- 5. Hyper-personalization and customer journey simulation are top expected use cases:** 69% of insurance leaders and 67% of life sciences marketers prioritize real-time customer journey simulation and hyper-personalization at scale as key quantum applications.
- 6. Current claims exceed hardware capability:** Commercial quantum advantage for marketing remains constrained by Noisy intermediate-Scale Quantum {NISQ} hardware limits: noise, low qubit counts, and high error rates. Most reported "revenue" comes from consulting and hardware sales, not deployed marketing applications.

Conclusion

Quantum Marketing and Real-Time Personalization represent a paradigm shift in how businesses interact with customers, leveraging quantum computing's immense processing power to deliver hyper-personalized experiences. By analyzing vast amounts of customer data in real-time, marketers can create tailored interactions that enhance engagement, drive conversions, and foster loyalty. This level of personalization was previously unimaginable with traditional computing

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methods, positioning quantum marketing as a game-changer in the digital landscape. The implementation of quantum marketing is not without challenges. Data privacy and security concerns, integration complexity, and the scarcity of quantum expertise pose significant hurdles for businesses. To overcome these obstacles, companies must invest in robust data infrastructures, collaborate with quantum experts, and prioritize developing talent with expertise in quantum technologies and marketing. Proactive strategies are essential for mitigating risks and unlocking the full potential of quantum marketing. Businesses that embrace quantum marketing and navigate its challenges effectively will be poised to gain a competitive edge in the market. By harnessing the power of real-time personalization, companies can deliver exceptional customer experiences, drive growth, and stay ahead in a rapidly evolving digital landscape. The future of marketing is increasingly quantum, and early adopters are likely to reap significant rewards.

Recommendations

- 1. Focus on hybrid quantum-classical pipelines:** Deploy quantum processors only for specific combinatorial sub problems like feature selection, clustering, and QUBO optimization. Keep data ingestion, encoding, and delivery on classical systems until hardware matures.
- 2. Build quantum-ready data infrastructure:** Structure customer data platforms to support high-dimensional feature vectors and real-time streaming. Quantum algorithms require clean, low-latency data pipelines to realize speed gains.
- 3. Pilot quantum-enhanced optimization for budget and channel allocation:** Test quantum algorithms on marketing mix optimization and A/B testing where the search space is large and evaluation must be near real time. Start with small-scale simulations before production use.
- 4. Invest in quantum literacy for marketing and data teams:** Quantum models break from classical intuition. Train staff on quantum probability, superposition, and uncertainty to interpret outputs correctly and avoid misapplication.
- 5. Establish clear evaluation criteria for quantum claims:** Demand intermediate technical milestones, error rates, and benchmark comparisons against classical baselines. Avoid vendors whose timelines promise 1000+ qubits and full fault tolerance within 2 years without a credible roadmap.

6. Prioritize use cases where real-time speed outweighs absolute accuracy: Quantum sampling can trade slight accuracy loss for faster inference. Target applications like dynamic pricing, fraud detection, and content adaptation where milliseconds matter more than 99.9% precision.

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