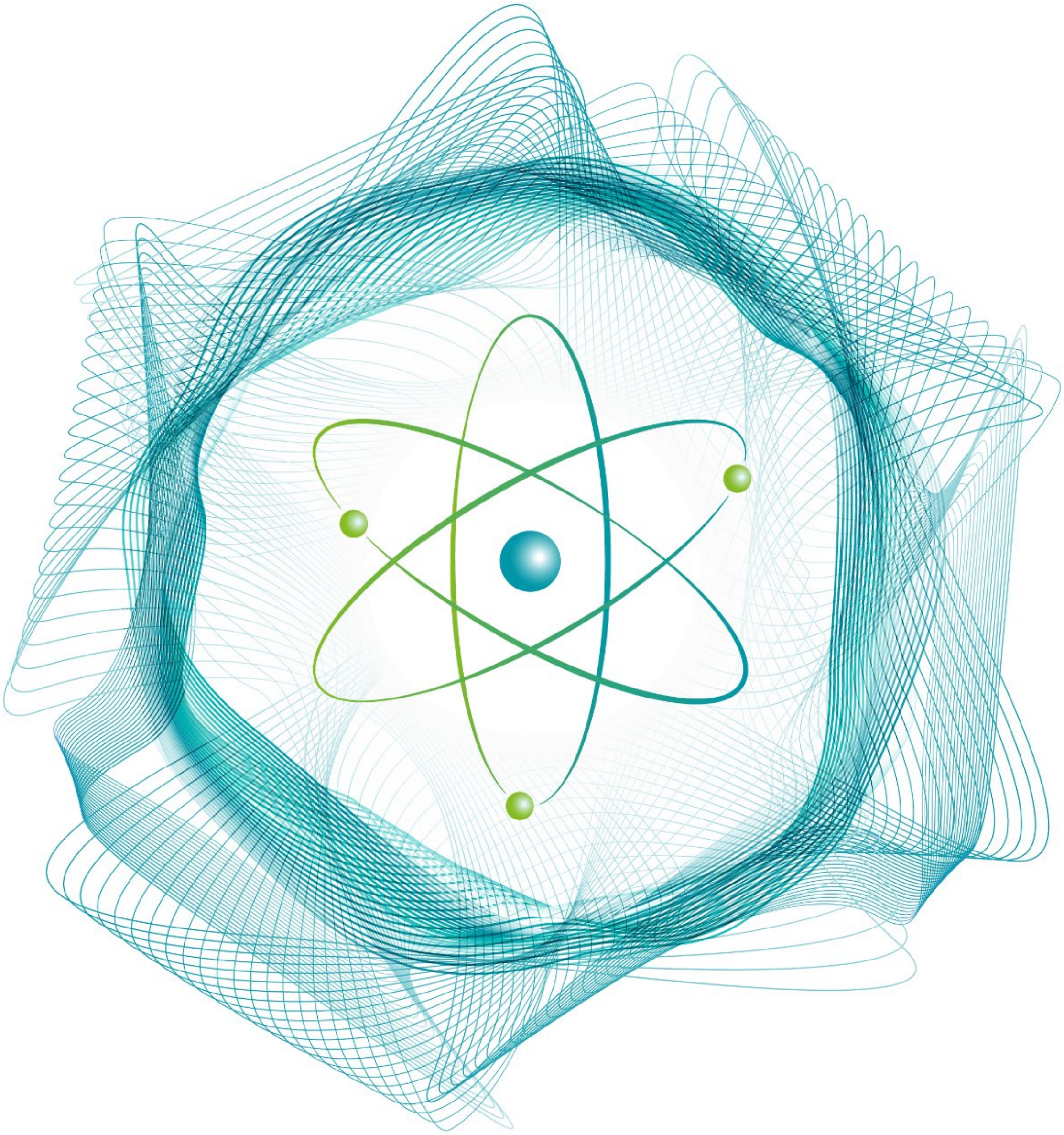

LSHC Industry Market Research

Market Analysis of Quantum Computing Use Cases

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Prepared by: Deloitte Consulting LLP

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Executive Summary

Quantum computing, a transformative computational approach, is on the brink of ushering in a new era of advanced computing. By performing calculations differently than today's computers, quantum computers may enable companies across the life sciences and health care industries to accelerate drug discovery, enhance diagnostic accuracy, optimize resource allocation, and much more. This report offers an accessible perspective on how quantum computing can be applied within the life sciences and health care ecosystem. The report prioritizes use cases by impact and feasibility, and aims to aid drug-makers, health care providers, and health insurance companies as they seek to understand and invest in quantum technology.

The life sciences and health care industries are particularly well-positioned to reap the potential benefits of these quantum computing advancements. There is a wealth of both existing and untapped use cases which can be addressed by quantum solutions. These include, but are not limited to, applications in optimization, machine learning, and simulation.

To better understand the nature of these opportunities, we evaluated over 50 sector-specific applications and consolidated them into a dozen categories of opportunities. For each of these categories, we evaluated a combination of business factors (i.e., potential improvement in patient outcomes, profitability impact, degree of regulation) and technical factors (i.e., scalability of existing solutions, the complexity of running the problem on a quantum computer, known likelihood of speedup).

Opinions and feedback from subject matter experts and industry leaders were incorporated to validate the findings, and we compared our results to surveys conducted with industry executives. This report summarizes and evaluates the most attractive life sciences and health care opportunities for quantum computing as determined by weighted analysis of business and technical factors.

The categories of use cases which have the highest business impact and technical feasibility include molecular simulations, rare disease demand forecasting, complex biotech production scheduling, predictive diagnostics, and many more. The top categories of use cases are further detailed in Section V, including the anticipated business benefits of sector-specific applications.

> *In the short term, we expect that quantum computing will positively impact our operations through combinatorial optimization. In the longer term, we expect the strongest impact to be on our approach to modeling with differential equations and matrix inversions.*
>
> – LSHC Industry Executive

Quantum Computing in Life Sciences and Health Care

The life sciences and health care industries are pivotal in advancing human health and well-being by continuously seeking innovative solutions to address complex biological and medical challenges. Quantum computing, with its potential to identify subtle data relationships and solve intricate problems, is poised to revolutionize these fields.

While there is significant optimism about the future uses of quantum computers in the health arena, at the time of this writing, production workloads are largely outside the capability bounds of today's hardware. The quantum computing industry is continuing to improve hardware and software to overcome the current challenges, a process referred to as constructing "logical qubits", or fault-tolerant quantum computers (FTQC). Moreover, future research may uncover software algorithms or approaches that substantively change the relative attractiveness of different use cases.

Despite the uncertainty as to when a quantum computer will be able to tackle production-scale problems, some near-term advantages can be obtained from developing internal talent in researching new algorithmic approaches. For instance, some "quantum inspired" algorithms may provide real advantage today in machine learning over today's techniques. In addition, identifying and mitigating suboptimal solutions to optimization problems, which are crucial for tasks such as optimizing clinical trial designs or improving the efficiency of health care delivery systems. As the technology continues to mature, the future of quantum computing in life sciences and health care holds promise for groundbreaking advancements, potentially transforming diagnostics, drug discovery, care delivery, and personalized medicine.

> *Quantum computing applications are still evolving in health care and life sciences, but promise to transform biomarker and drug discovery, particularly when combined with artificial intelligence capabilities through quantum centric supercomputing.*
>
> – LSHC Industry Executive

Complex Problems in Life Sciences & Health Care

As quantum computing technology matures, the potential applications within life sciences and health care are taking shape and beginning to attract investment. These applications are largely centered around three key areas: optimization, machine learning, and simulations.

Optimization

Optimization is critical in numerous aspects of life sciences and health care, where efficient resource management and process improvements can lead to significant advancements and cost savings. However, classical algorithms have constraints that limit their usefulness as the size and complexity of problems increase. For instance, optimization engines can get 'stuck' exploring suboptimal results, overwhelmed by the explosion of exponential possibilities, or simply not provide solutions in the time available.

In the biopharma sector, optimizing manufacturing processes and production scheduling can reduce waste and downtime while ensuring the safety and efficacy of final products. Similarly, optimizing clinical trial designs helps in selecting the most suitable patient cohorts and clinical sites, reducing trial durations, and improving the chances of success and regulatory approval.

Health care providers can benefit from optimization in various operational areas. For instance, optimizing the scheduling of surgeries and other medical procedures leverages operating rooms and medical staff more efficiently, reducing patient wait times and improving care delivery. Resource allocation optimization also helps in managing the inventory of medical supplies and pharmaceuticals, ensuring that critical items are always available when needed.

For health care payers, optimization techniques are essential for managing financial risk and streamlining claims processing. For instance, optimizing premium pricing and plan design based on risk pools helps ensure financial sustainability with comprehensive care.

Machine Learning

Although classical machine learning has been transformative in enabling the analysis of vast datasets to enhance decision-making in the life sciences and health care industries, these tools face limitations in scalability, accuracy, and handling of exponentially complex data structures. For instance, classical methods require increased computational power and longer training times to handle the high-dimensional data inherent in molecular modeling; they also require manual feature engineering, which can be unsustainable when processing complex non-linear relationships in datasets. Quantum machine learning (QML) algorithms, which leverage the power of quantum computing, can capture complex, non-linear relationships and address these challenges with enhanced predictive capabilities.

QML overcomes some of the limitations of classical machine learning. With the ability to process and analyze complex datasets more efficiently, QML can empower more accurate predictive models and enhance their ability to uncover insights from complex biological data that are currently beyond the reach of classical methods. This advancement could significantly accelerate drug discovery, advance personalized medicine and improve overall health care delivery.

In the biopharma industry, machine learning algorithms are used to analyze and identify hidden patterns in genomic and proteomic data to facilitate discovery of new drug targets and predict the efficacy of new compounds. Deep learning models, for example, can be trained to recognize patterns in biological data that correlate with disease states, helping researchers identify novel therapeutic targets. These models are also used to predict patient responses to treatment based on their individual genetic profiles, enabling development of personalized medicines. Each of these applications rely on accurately capturing complex, non-linear relationships in medical data, which may exceed the limitations of classical models; QML, however, offers an advantage through use of quantum entanglement to manage interdependencies among clinical features, leading to more precise classification and prediction.

For health care providers, machine learning is used to enhance diagnostic accuracy by analyzing medical images, electronic health records, real-world evidence, clinical trial records, and other patient data. Convolutional neural networks (CNNs) can facilitate earlier diagnosis through early detection in medical imaging scans, while predictive analytics help identify patients at high risk of developing chronic conditions, allowing for proactive interventions and better management of patient health. Despite their benefits, these classical models require significant computational resources and time to train and have been known to overfit to training data, resulting in poor generalization to new, unseen datasets. QML algorithms, conversely, can accurately predict and extrapolate patterns from limited training data, making them especially beneficial for diagnosing rare diseases.

Health care payers also leverage machine learning algorithms for fraud detection and risk management, which can be used to identify unusual patterns in claims data.

These models, however, may struggle to efficiently analyze the intricate interdependencies among variables in claims to identify abnormalities. This issue is exacerbated by the inherent imbalance in training data due to the relative rarity of fraudulent claims compared to legitimate ones. QML's superior pattern recognition and anomaly detection offers a clear advantage over the existing classical systems.

Simulations

Simulations play a vital role in advancing medical research and improving patient outcomes by modeling complex biological systems and business networks. However, current simulations face significant challenges, particularly in accurately modeling interactions at the molecular level. Traditional computational methods often fall short in precisely predicting the behavior of molecules, especially in complex biological environments. This limitation is crucial because accurate chemical simulations are essential for understanding fundamental processes such as enzyme reactions, protein folding, and drug-receptor interactions. Inaccurate simulations can lead to suboptimal drug designs and ineffective therapies, ultimately impacting patient outcomes and increasing development costs.

Quantum simulations offer a promising solution to these challenges by leveraging the principles of quantum mechanics to provide more precise and detailed models of molecular interactions. This advancement is particularly important in drug discovery, where understanding the exact behavior of molecules can lead to the development of more effective, targeted, and potentially lifesaving therapies. As quantum computing technology continues to evolve, it holds the potential to revolutionize simulations in life sciences and health care, enabling breakthroughs in medical research and significantly improving patient care.

In biopharma, simulations of molecular interactions help researchers understand how new compounds will interact with biological systems, accelerating the development of effective therapies. Molecular dynamics simulations, for example, predict the binding affinity of drug candidates to their target proteins, guiding the design of more potent and selective drugs. Simulations also model the pharmacokinetics and pharmacodynamics of new drugs, predicting their behavior in the human body and informing dosage and administration strategies.

Health care providers use simulations to model patient outcomes under different treatment plans, aiding in the development of personalized medicine approaches. Computational models simulate the progression of diseases such as cancer under various therapeutic regimens, helping clinicians choose the most effective treatment for each patient.

Health care payers use simulations to predict the impact of policy changes on health care costs and patient outcomes. Agent-based models, for instance, simulate the behavior of patients, providers, and payers in response to changes in insurance coverage or reimbursement policies, helping to design more effective and sustainable health care systems. Simulations also assess the long-term financial implications of new health care technologies and treatments, guiding investment decisions and resource allocation.

> *We're actively exploring the use of quantum computing to transform our R&D pipeline, particularly in drug discovery and supply chain optimization. Through partnerships with leading quantum innovators, we're piloting quantum algorithms to simulate molecular interactions with unprecedented precision and evaluating quantum approaches to optimize our manufacturing processes. These early steps are laying the foundation for a quantum-driven future in pharmaceuticals.*
>
> –LSHC Industry Executive

Use Case Ranking Methodology

Ranking Approach

To rank the use cases, we developed an analytical approach that included both quantitative and qualitative aspects. We began by conducting market research, reviewing existing research, and interviewing subject matter experts across life sciences and health care to gain insights into technology gaps and opportunities within industry value chains. Through this process, we identified over 50 unique quantum computing sector-specific applications.

Our evaluation methodology assessed each potential application against five business criteria, including profitability impact, adoption feasibility, and regulatory barriers, as outlined in Table 1. We then assessed the quantum computing requirements to achieve the desired business impact and identified technological barriers to implementation. Applications were further evaluated on five technology criteria including existing limitations, quantum processing complexity, and expected use case improvement, as detailed in Table 2. By generating weighted scores across both business and technology criteria, we determined the overall prioritization ranking. The top six application areas were selected for further in-depth analysis within this report.

Ranking Criteria

Table 1: Business criteria for ranking quantum computing use cases in the life science and health care industries

Business Criteria	Description
Impact of Greater Accuracy	Degree to which greater accuracy is material and would lead to better business outcomes
Impact of Greater Speed	Degree to which greater processing speed would lead to positive business impact
Profitability Impact	Financial impact based on quantum solutions would increase revenue or decrease cost
Adoption Feasibility	Organizational feasibility of implementing a quantum solution to enhance/replace classical solutions (e.g. technical, workforce, financial)
Anticipated Regulatory Barriers	Degree to which regulatory and legal conditions will limit business impact of quantum solutions

Table 2: Technical criteria for ranking quantum computing use cases in the life science and health care industries

Technical Criteria	Description
Limitations of Existing Technology	Extent that limitations of classical computing create barriers to business goals
Processing Complexity of Quantum Solution	Number of QPU required to implement applicable (with fewer qubits being favorable)
Estimated Improvement Impact	Degree of improvement over classical methods provided by applicable quantum solution
Certainty of QC Improvement	Certainty that quantum solution will lead to material improvement over classical methods
Current Maturity of Quantum Solution	Estimated timeline for commercial scalability of applicable quantum solution

Additional Assumptions

Current Quantum Calculation Limitations

Quantum computers utilize quantum bits, or "qubits," as the fundamental elements of computation. The qubits in today's machines are often referred to as "physical qubits," while the theoretical construct of error-free, fault-tolerant qubits are known as "logical qubits." Current approaches to building logical qubits typically involve combining multiple physical qubits in specific ways to enhance the quality of output, akin to the way parity checks work in classical computers.

The number of physical qubits required to produce a single logical qubit is currently a topic of ongoing research and debate. Quantum error correction (QEC) is a fundamental aspect of quantum computing, designed to protect quantum information from errors due to decoherence and other quantum noise. Unlike classical bits, which are either 0 or 1, qubits can exist in superpositions of states, making them highly susceptible to errors. Quantum error correction codes are essential because they enable the detection and correction of these errors, ensuring the reliability and stability of quantum computations. The most well-known method for quantum error correction, known as the ‘surface code’, requires approximately one thousand physical qubits to form a logical qubit. And ongoing research indicates this number can be further reduced through Cat Qubits, low-density parity check code (LDPC), or a combination of both in QEC. Nonetheless, the required number of physical qubits can vary significantly depending on the types and characteristics of quantum hardware and the specific applications on which they’re used.

Additionally, qubits must interact through "gates," and the number of sequential operations these gates perform is referred to as "gate depth." High gate depth can pose challenges for current hardware, similar to the challenges posed by requiring a large number of qubits. Some calculations may necessitate relatively low qubit counts but high gate depth, leading to different types of computational complexity. Ultimately, the number of qubits and the gate depth required to solve problems are critical factors, as they determine how soon existing quantum computers might be capable of addressing practical business challenges.

Another critical issue is quantum decoherence, where qubits lose their quantum state due to environment interactions. This loss of coherence restricts the duration available for computations and heightens the probability of errors.

In summation, the scalability limitations of quantum computing stem from the trade-off between the number of qubits required, the gate depth required, and the time limits imposed by decoherence. The speed at which solutions to these challenges are discovered will determine how soon quantum computers will be practical and scalable in solving more complex business problems.

Current State of Quantum Algorithm Development

Technical considerations and criteria used to evaluate these use cases were formulated based on the current understanding of classical and quantum approaches to relevant applications as of Q1 2025. Given the rapid advancements in quantum computing, qubit and gate depth requirements, algorithmic strategies, and overall outlook may undergo significant changes. Consequently, future analyses might present substantially different conclusions compared to the time of this current publication.

Whenever feasible, we assume that use cases with multiple potential pathways—whether through various algorithmic approaches or lower qubit and gate depth thresholds—generally have a higher likelihood of being realized in the near future. This flexibility in approach enhances the probability of successful implementation as quantum technology continues to evolve.

Summary of Top Use Case Categories

Table 3: Ten Use Case Categories, including descriptions type of quantum solution

Use Case Category	Quantum Type	Sectors	Category Description
Population Selection Optimization	Optimization	Life Sciences HCP Plans & Payers	Improve targeting and resource allocation in cohort-based business decisions (e.g., clinical trials, health care delivery, and group underwriting) based on nuanced population attributes
Scheduling Optimization	Optimization	Life Sciences HCP	Enhance resource utilization through optimization of production scheduling and workforce management based on resource availability and demand (e.g., job-shop, nurse scheduling)
Demand & Utilization Forecasting	Machine Learning	Life Sciences HCP Public Health	Enhance forecasting accuracy in predicting drug demand, patient utilization, and disease spread by analyzing complex, non-linear data
Predictive Cohort Analysis	Machine Learning	HCP Life Sciences	Enhance patient stratification and targeted interventions by leveraging advanced analytics to identify, segment, and predict outcomes for distinct population cohorts across diverse clinical and real-world health data sources
Molecular Interaction Modeling	Simulation	Life Sciences	Simulate complex molecular interactions to identify targets compounds, improve disease understanding, and accelerate drug discovery and development
Risk Modeling	Simulation	Plans & Payers Life Sciences	Measure nuanced risk factors and simulate scenarios to enhance risk modeling in group underwriting & plan design and supply chain management
Genomic Analysis	Machine Learning	Life Sciences	Enhance pattern recognition and predictive analysis of complex genomic data, accelerating disease understanding, identification of genetic risk factors, and development of next-gen therapies
Predictive Diagnostics	Machine Learning	HCP	Improve diagnostic accuracy and personalized treatment plans by analyzing vast clinical and RWE datasets to identify diseases, predictive attributes, and underlying mechanisms
Anomaly Detection	Machine Learning	Plans & Payers Life Sciences	Identify unusual patterns and deviations in health care data to detect potential issues such as equipment malfunctions, unusual patient behavior, or irregularities in clinical trial data
Claims Adjudication	Machine Learning	Plans & Payers	Streamline process of evaluating and processing insurance claims by accurately verifying and validating claim details to reduce errors, accelerate settlements, and enhance overall efficiency

Top Categories of Use Cases

Optimization

Overarching Technical Considerations

Many complex optimization problems—ranging from portfolio management in finance to production and labor scheduling in industry—can potentially benefit from quantum algorithms such as the Quantum Approximate Optimization Algorithm (QAOA) and Grover Adaptive Search (GAS), which offer theoretical speedups over classical methods. However, the practical use of these algorithms is currently limited by the significant circuit depths required, which exceed the capabilities of today's quantum hardware. To address real-world, large-scale problems and realize the full potential of these algorithms, advancements in logical qubits and quantum error correction are essential. In the near term, classical heuristics and hybrid quantum-classical approaches will remain important, but long-term progress in error correction and hardware will be critical for quantum optimization to deliver meaningful business value.

Population Selection Optimization

Description

Optimizing business decisions based on population attributes is an essential activity that drives performance for companies across the life sciences and health care industries. In areas as diverse as clinical trial design, health care delivery, and underwriting decisions, companies can improve outcomes and reduce costs by accurately identifying and targeting cohorts to more efficiently allocate resources, improve patient outcomes, and tailor services to meet the unique needs of different groups. Despite their diversity, these activities all focus on analyzing and grouping population segments to reduce risk and maximize business outcomes, similar to the way financial institutions group complex assets of varying performance to maximize return, an activity which has already reaped benefits from quantum-based solutions. The expected quantum-enhanced benefits include better resource management, increased operational efficiency, and more personalized and impactful health care and insurance solutions.

Sector Applications & Industrial Importance

Public and private health insurance providers must design health plans, price premiums, and implement utilization controls that reflect the unique attributes of specific populations, ensuring that coverage is both comprehensive and financially sustainable. Accuracy is critical for competitiveness and financial stability, with some studies indicating that initially underpriced premiums can lead to 20-30% increases in subsequent years to cover the shortfall, creating market volatility and consumer dissatisfaction in its wake. For drug developers, the selection of ideal patient cohorts and clinical trial sites is paramount, as it directly influences trial success rates and R&D costs. For instance, it is estimated that 30% of Phase III trials extend beyond initial deadlines—often due to recruitment challenges and sub-optimal design—with each additional day a drug spends in developing costing millions and seriously cutting into R&D return on investment.[1] Health care providers benefit from optimally targeting patient cohorts with high risk of discontinuing care based on indicators such as co-morbidities, lifestyle, socioeconomic status, or likelihood of adverse treatment effects. Not only can a targeted approach improve resource efficiency, but it can have a serious impact on the overall health system, with hospital readmissions and medical costs associated with treatment nonadherence estimated to cost the U.S. health care system $500 billion annually.[2]

Scheduling Optimization

Description

Optimized scheduling is a crucial function for enhancing efficiency, managing costs, and ensuring quality across numerous activities in the life sciences and health care industries. Precise scheduling is essential for coordinating complex processes, optimizing resource allocation, and improving operational workflows, and deficiencies in these areas can lead to additional costs, lost productivity, and increased health and safety risks. These challenges fall into two main categories: "job-shop" scheduling in production and workforce scheduling. Job-shop scheduling refers to the process of determining the most efficient sequence of "jobs" processed on multiple machines, with each job having its own specific order of operations. In life sciences manufacturing, many therapeutics and molecular drugs are time-sensitive, making the task of optimizing the sequence of steps in the production process highly critical. Meanwhile, given the current turnover rates for nurses hovering as high as 37%, optimizing schedules is becoming an important problem for many health care providers to maintain quality-of-care and manage risk of burn-out.[3] Overall, these two scheduling problems are known to be computationally difficult, and finding better solutions would have important impacts on the industry.

Sector Applications & Industrial Importance

Precise scheduling optimization is crucial in both manufacturing and workforce contexts due to the complexity and high stakes involved. In the growing field of personalized medicine manufacturing (e.g., gene and cell therapies), production slot scheduling ensures that each batch is customized for individual patients, requiring meticulous coordination of resources, equipment, and timing to meet stringent safety and regulatory standards. Similarly, fill-finish-pack scheduling for pharma and med-tech manufacturers (e.g., biologics, injectables, implants, etc.) involves managing multiple manufacturing stages and ensuring timely availability of materials to deliver thousands of potential SKUs to hundreds of markets. In both manufacturing applications, suboptimal scheduling can lead to wasted batches—which in the case of personalized medicines can cost more than $500k per lost dose and millions in lost revenue.[4]

In health care settings, effective labor scheduling is vital in balancing staff availability with patient needs to optimize the use of rooms and equipment and minimize waiting times. The costs of sub-optimal labor scheduling add up; in the U.S., hospitals on average incur costs of over $3,000 per inpatient day, while the estimated cost of unused operating time can cost hospitals up to $2,000 per hour.[5]

> *"In life sciences and health care, I'm particularly excited by the potential of quantum computing to extract insight from sparse or noisy data—whether in early-stage drug discovery, modeling protein interactions, or personalizing treatments based on complex clinical and genomic inputs. These are areas where conventional methods struggle with combinatorial complexity, and quantum approaches may offer a powerful advantage."*
>
> – Quantum Computing Industry Executive

Machine Learning

Overarching Technical Considerations

Quantum machine learning (QML) algorithms have promising applications in health care and pharmaceutical demand forecasting, as well as in analyzing complex medical datasets such as genomics and electronic health records. These algorithms, including quantum kernel methods, quantum neural networks, and newer approaches like Quantum Reservoir Computing, can capture intricate relationships in data and may outperform classical methods, sometimes with less training data. However, successful adoption of QML requires robust quantum hardware and software infrastructure, high-quality and well-encoded data, and expertise in both quantum computing and domain-specific areas. As QML methods continue to advance, their ability to integrate heterogeneous data and provide explainable results could offer significant advantages, but practical deployment will depend on overcoming current technical and scalability challenges.

Demand & Utilization Forecasting

Description

Accurate demand and utilization forecasting is essential for health care providers and pharmaceutical companies to allow efficient resource allocation and optimized service delivery. Hospitals must predict equipment, space, and labor needs to meet patient demand, while drug and device makers require accurate forecasting to optimize production, supply chain management, and commercial resource allocation. This is especially challenging with forecasting demand for rare or emergent diseases or in volatile markets. In both cases, the scarcity and increasing complexity of data inputs may create challenges for many classical machine learning models when dealing with emerging events.

Sector Applications & Industrial Importance

Forecasting demand is essential for R&D planning and commercial resource allocation for life sciences companies, yet accuracy remains a challenge for classical techniques due to the scale and complexity of data. Forecasting models rely on myriad market-specific inputs (including epidemiology trends, diagnosis rates, prescribing behavior, clinical guidelines), yet these data sets vary in reliability and quality, especially for rare diseases. Inaccuracies can lead to reduced access to life saving medicines for patients, as well as significant financial costs to drug-makers, with one recent estimate estimating that inaccurate demand forecasting can reduce annual revenue by up to 10% due to lost sales opportunities.[6] Quantum machine learning algorithms can overcome these limitations by processing complex patterns with less training data, providing precise demand forecasts.

In the health care context, hospitals often rely on static models to predict resource utilization, which lack the flexibility to adapt to real-time patient demand and facility capacity. On the one hand, this can lead to stretched capacity and worsened patient outcomes due to unavailability of equipment (e.g., ventilators), or conversely, the underutilization of resources, which is estimated to cost the average hospital $1.4M for every percentage drop in utilization.[7] Quantum-enhanced prediction techniques can improve capacity efficiency by predicting utilization needs at time of intake based on presenting symptoms.

> *"Clinical trials, which account for 70% to 75% of drug development costs, present tremendous opportunities for quantum computing. Advanced simulations can optimize patient enrollment and site selection, while quantum Markov Chain Monte Carlo methods address complex combinatorial challenges. Additionally, Quantum Machine Learning is already demonstrating improved performance over classical methods, particularly for small datasets."*
>
> – LSHC Industry Executive

Predictive Cohort Analysis

Description

Biotech and med-tech companies and health care providers often face challenges in identifying detailed population attributes essential for predicting health risks, disease progression, and treatment outcomes. Machine learning techniques can significantly enhance and expedite these processes by performing tasks such as classification and clustering to identify appropriate population segments or predict properties associated with specific groups. For instance, ML algorithms can help to identify population attributes that make patients suitable for gene-therapy treatment. Given the diverse and complex nature of data sources like individual and public health records, genomics, clinical research, and patient-generated data, sophisticated machine learning models are necessary to execute various unsupervised or supervised learning tasks. However, these models often require extensive training data, which may not be readily available due to the lack of diagnoses or the rarity of certain diseases.

Sector Applications & Industrial Importance

Patients are often diagnosed based on a comparison of presenting symptoms at intake, diagnostic tools (e.g., medical imagining), and clinical guidelines, however those with rare diseases often cycle through numerous therapies before finding an effective one; the impact of suboptimal diagnoses can be dire, with a 2015 study finding that diagnostic errors contributed to 10% of patient deaths and up to 17% of adverse events in hospitals.[8] Predictive cohort analysis could improve and personalize treatment decisions by analyzing patient records alongside vast data sources—such as clinical guidelines, real-world evidence, trial data, and medical images—to predict risk factors for specific patient groups.

Another challenge is that patients in rural areas often miss out on next-gen therapies because they are never identified as candidates by advanced academic research hospitals where gene and cell treatments are typically concentrated; the result can be worsened health outcomes and a reduced pool of candidates for studying life-saving therapies. In fact, as few as 3% of clinical trial participants for cutting-edge treatments come from rural areas.[9] Quantum-enhanced algorithms may address this gap by analyzing vast troves of electronic health records to identify candidates for gene and cell therapies through predictive analysis.

> *Beyond clinical trials, quantum computing is driving innovation in molecular development. While much of the current focus remains on small molecules, technology is increasingly being applied to the more complex challenges posed by larger molecules, opening new frontiers in pharmaceutical research.*
>
> –LSHC Industry Executive

Simulation

Molecular Interaction Simulations

Description

Computer aided drug design (CADD) plays a crucial role in various aspects of the life sciences sector, including research & development (R&D), and production synthesis. These methods are generally employed to perform significant tasks such as predicting the structure of complex biological molecules and modeling reactions. Despite their power, current computational chemistry techniques only approximate many natural processes, such as chemical and biological effects, which can lead to inaccurate predictions. Data-driven methods like AlphaFold have been used to predict numerous complex protein structures; however, their predictive accuracy depends heavily on the availability of sufficient training data, which can be a critical issue for diseases caused by genetic mutations. Quantum computing offers the potential to simulate many of these natural phenomena more accurately, making it an ideal candidate to accelerate the silico drug discovery process.

Sector Applications & Industrial Importance

Accurate prediction of protein structures and DNA/RNA within the drug discovery pipeline is crucial for understanding disease mechanisms and designing personalized therapeutics. Traditional methods like molecular dynamics (MD) are commonly used for structure prediction, but they are heuristic and often depend on expert knowledge or existing laboratory data. AI tools, such as AlphaFold, have made significant strides in this field; however, they are limited by their training data, which may lack sufficient examples of specific mutations. This limitation can hinder their ability to generalize novel sequences, particularly in the prediction of neurodegenerative diseases like Alzheimer’s and Parkinson’s. These constraints come at a cost; for example, validating protein structures through cryo-EM can cost up to $500,000 per structure.[10]

Beyond structure prediction, simulation methods can model pharmacokinetics and dynamics to predict drug properties such as efficacy and toxicity before clinical trial. These methods also aid in the synthesis of new drugs by effectively simulating the required chemical processes. Computational approaches can estimate the binding strength of a molecule to its biological target in the human body, informing drug dosage optimization to maximize clinical trial success. Consequently, accurate CADD methods can shorten the drug discovery process, reduce costs, and minimize unwanted side effects. In fact, leveraging accurate CADD can significant the potential success of many clinical trials, which have a failure rate of 70% due to problems like drug efficacy and safety.[11] Beyond discovery, simulations are equally important to med-techs, where chemical manufacturing simulations are used to design precise production processes and conditions via prediction of molecular interactions in steps across the supply chain. Lost batches due to production error can cost manufacturers millions in production delays and foregone revenue, making chemical manufacturing simulations a critical tool in risk mitigation.

Technical Considerations

Quantum simulation is one of the most promising applications for quantum computers, leveraging their intrinsic quantum properties to study natural phenomena. Specifically, molecular and chemical interactions can be modeled using algorithms such as the Quantum Variational Eigensolver (VQE) and Quantum Phase Estimation (QPE) to simulate molecules' electronic and chemical properties. These quantum algorithms are designed to solve complex equations governing the atomic structures within molecules. VQE, a hybrid quantum-classical algorithm, is tailored for Noisy Intermediate-Scale Quantum (NISQ) computers. However, several challenges hinder their application to industry-relevant molecules in life sciences. These challenges include the difficulty in accurately loading initial states that approximate the correct ground state of molecules, the impact of noise in NISQ devices that prevents VQE from converging to the correct solution, and the complexity of designing quantum circuits with high circuit depths. Conversely, QPE, which offers a polynomial advantage in molecular simulations, is designed for Fault-Tolerant Quantum Computers (FTQC).

Recent advancements in quantum simulation algorithms suggest there are benefits quantum-classical hybrid solutions that leverage both quantum and high-performance computing to explore more complex molecules. Nevertheless, due to the significant resource requirements for error correction, the full potential of quantum simulations remains in the future, contingent on the development of FTQC devices with over 1,000 logical qubits.

Risk Modeling

Description

Risk modeling plays an important role in life sciences and health care industries, with typical applications including supply chain risk modeling for drug and device manufacturing, or cohort risk prediction for health plans and payers assessing coverage pools. Current machine learning solutions employ regression analyses, decision trees, and neural networks to predict potential outcomes based on patterns in historical data. However, these models are limited by the vast computational power required for capturing complex interactions among variables and practical concerns, like the length of time to simulate multiple scenarios. Quantum simulations may drastically improve these processes by precisely measuring risk factors and simulating potential outcomes with greater accuracy. This advanced capability allows organizations to make better-informed decisions, enhancing supply chain resilience, improving patient outcomes, and ensuring financial stability. By processing vast datasets and uncovering intricate patterns, quantum computing offers a powerful edge in risk modeling.

Sector Applications & Industrial Importance

Risk modeling is crucial within the life sciences and health care industry for ensuring stability, efficiency, and proactive decision-making. Public and private insurance providers rely on accurate risk assessments to inform plan design, underwriting, premium pricing, and utilization management controls, though classical modeling techniques are less accurate in measuring risk attributes for predicting outcomes in narrower populations. Drug and medical device manufacturers can also benefit from quantum-enhanced risk modeling by using simulations to predict and proactively plan for various supply chain disruption scenarios (e.g., raw material shortages) and their impacts through the enterprise; such disruptions can cause drug-makers to lose up to 20% of their annual revenue, making accurate enterprise risk forecasting critical for sustainable profitability.[12] Last, health care providers and payers alike use models to predict disease spread to enable effective containment strategies, treatment guidelines, and capacity management. Though classical machine learning modeling is an important tool, quantum computers can simultaneously simulate multiple scenarios to facilitate better preparedness.

Technical Considerations

Quantum algorithms, such as Quantum Amplitude Estimation (QAE) which can significantly enhance risk analysis and estimation by accelerating Monte Carlo simulations, offering a quadratic speedup. QAE leverages fast loading of classical data as distributions and uses Grover's search algorithm to amplify amplitudes for optimal value estimation. However, QAE's near-term applications are limited due to its high circuit depth, and it may not be scalable in these industry applications until quantum computers with a sufficiently high number of logical qubits and fault tolerant capabilities are developed. Recent advancements, such as Quantum Signal Processing (QSP), have been proposed to perform amplitude estimation with shorter circuit depth, albeit requiring more queries to amplify the amplitudes. QSP can reduce the resource demands for quantum error correction, potentially enabling quicker adoption of quantum algorithms for risk analysis in the future.

> *Perhaps the most exciting is the convergence of quantum computing and artificial intelligence, particularly through the integration of quantum technologies with Large Language Models. As research in quantum transformers advances, we are moving toward a future where quantum computing and AI are deeply interconnected, unlocking unprecedented possibilities for scientific discovery and innovation.*
>
> –LSHC Industry Executive

Additional Top Use Case Categories

Genomic Analysis

In the realm of genomic analysis, quantum machine learning offers transformative applications for **early genomic screening**, **genetic sequencing and profiling**, and **omics data analysis and prediction**. Advanced QML algorithms, such as quantum neural networks (QNNs), can extract better insights and patterns from complex genomic data. These enhanced insights can accelerate disease understanding, treatment development, and the application of next-generation therapies to a broader population.

Predictive Diagnostic Support

Quantum machine learning (QML) algorithms can significantly enhance predictive diagnostic support by enabling better decision-making for health care providers. In the realm of **clinical decision support**. QML can analyze patient medical history and lab tests to recognize diseases and identify underlying mechanisms within complex datasets, aiding doctors in making more accurate diagnostic decisions. Additionally, QML can provide **personalized health insights** by considering individual factors such as lifestyle, diet, and the likelihood of experiencing adverse effects. This dual approach is particularly beneficial for rare and emerging diseases where data is scarce, ultimately leading to more precise diagnoses and tailored treatment plans that improve patient outcomes and care quality.

Anomaly Detection

Quantum machine learning (QML) can significantly enhance anomaly detection in various health care and pharmaceutical applications. For payers, QML can improve **payment integrity controls** and **fraud detection** in health insurance claims by identifying outliers and anomalies through both supervised and unsupervised learning, enabling reductions in waste, fraud, and abuse, and ensuring accurate disbursements, thereby avoiding overpayments or penalties. In the context of drug and treatment manufacturing, QML can **facilitate predictive quality control** by detecting problems earlier in the production process. This proactive approach helps maintain high-quality products and prevents wasted batches, ultimately reducing additional costs and ensuring the efficacy of next-generation therapies.

Claims Adjudication

Quantum machine learning (QML) algorithms can enhance claims adjudication processes through **predictive claims processing** by accurately determining optimal next best actions on claims based on complex coverage and diagnostic criteria. These advanced algorithms ensure precise coverage decisions by processing a series of inputs, thereby enhancing the efficiency and accuracy of claims management. Additionally, certain QML models offer **better decision explainability** compared to classical black box models, while maintaining high performance. This transparency is crucial for providing clear reasoning behind claim decisions, reducing the number of appeals and call-center inquiries, and ultimately improving the reputation and trustworthiness of the insurance provider.

Conclusion

Quantum computing is a transformational technology that may provide compelling value to applications across the life sciences and health care ecosystem by solving complex technical and business challenges. As we stand on the brink of what may represent a new era in advanced computing, it is important that leaders in these industries actively engage with the possibilities this technology presents.

From the acceleration of drug discovery and enhancement of diagnostic accuracy to the optimization of resource allocation and clinical trial designs, quantum computing may offer unprecedented opportunities for future growth and innovation. Despite the current limitations of quantum computers, the rapid pace of research and development suggests that these challenges are not insurmountable.

This analysis of dozens of potential sector-specific applications, and the identification of the most impactful and feasible use case categories, provides a roadmap for exploration and investment. The potential of quantum computing to improve outcomes in areas as diverse as precision chemical manufacturing and enterprise risk modeling, or its power to accelerate drug discovery and the development of next-generation personalized medicines, is a prospect too significant to overlook.

The future of quantum computing is dynamic and rapidly evolving. Industry leaders should plan to remain agile and open-minded, to not just adapt to, but shape the future uses of these emergent technologies. As quantum solutions and capabilities continue to mature, the viability of individual applications will evolve, presenting new opportunities and challenges. Innovative leadership is not just about understanding and investing in quantum computing as a one-time activity but about shaping and leading its trajectory.

The development of quantum computers and their capabilities is continuing at a rapid pace. As we navigate this exciting frontier, let us not forget the potential it holds, not just for the future of health and medicine, but for the world at large. Quantum computers are not an evolution from our traditional computers; they are something new and different. Working together, we can help shape the future of both quantum computing and the life sciences and health care industries.

> *The potential of quantum computing to revolutionize drug discovery and personalized medicine is incredibly exciting. By enabling precise molecular simulations, quantum technology could slash the time and cost of developing new drugs, making treatments for complex diseases more accessible. We're also thrilled about its ability to optimize our entire value chain, from trials to distribution, driving efficiency and better patient outcomes*
>
> – LSHC Industry Executive

Appendix A: LSHC Sectors

Sectors in Life Sciences & Health Care

Life Sciences

Biopharma & Next-Gen Therapy

Biopharma companies and next-generation therapy manufacturers focus on developing new drugs and treatments, including personalized medicine and gene therapies. These organizations are at the forefront of scientific innovation, striving to address complex molecular and genetic challenges. Their efforts are crucial in bringing new, life-saving therapies to market and improving patient outcomes.

Med-Tech

Med-tech firms create medical devices and diagnostic tools that enhance patient care. This segment is characterized by its focus on innovation in medical imaging, diagnostics, and therapeutic devices. These companies play a critical role in advancing health care technology, providing tools that enable more precise and early detection of diseases, as well as improved treatment options.

Health Care Providers

Health care providers, including hospitals and clinics, deliver essential patient care services. This segment is crucial for the implementation of treatment plans and the management of patient health. Providers are responsible for a wide range of services, from routine check-ups to complex surgical procedures, ensuring that patients receive the care they need.

Health Care Payers

Health care payers, such as public and private health plans and insurance providers, manage health care costs and ensure access to medical services. This segment is vital for financial risk management and the optimization of insurance models. Payers work to balance the cost of care with the need to provide comprehensive coverage, playing a key role in the overall health care system.

Appendix B: Glossary

1. Computer Aided Drug Design (CADD)

The use of computational methods and tools to design and optimize drug candidates, predicting their interactions with biological targets

2. Convolutional Neural Networks (CNN)

A class of deep learning algorithms primarily used for analyzing visual data, recognizing patterns, and making predictions based on image inputs

3. Decoherence

The loss of quantum coherence, where quantum systems lose their ability to exhibit quantum behavior and behave more classically due to interactions with their environment

4. Deep Learning Models

A subset of machine learning models that use neural networks with many layers to learn and make predictions from large amounts of data

5. Fault-Tolerant Quantum Computers (FTQC)

Quantum computers designed to perform reliable computations even in the presence of errors, using logical qubits that are protected by error correction codes

6. Fault-Tolerant Quantum Computing (FTQC) Hardware

The physical components and systems required to build quantum computers that can perform fault-tolerant operations, ensuring reliable and accurate computations

7. Gate Depth

The number of quantum gates (operations) applied sequentially in a quantum circuit, affecting the overall complexity and execution time of quantum algorithms

8. Gradient Descent-Based Methods

Optimization techniques used in machine learning to minimize a function by iteratively moving towards the steepest descent, adjusting parameters to reduce error

9. Grover Adaptive Search (GAS)

A quantum algorithm that extends Grover's search algorithm, used for finding solutions to unstructured search problems more efficiently than classical methods

10. Heuristic Solvers

Algorithms that find approximate solutions to complex problems through trial and error, often used when exact solutions are computationally infeasible

11. Logical Qubits

Qubits that are encoded using multiple physical qubits and error correction codes to protect against errors, enabling reliable quantum computations

12. Low Density Parity Check Code (LDPC)

A type of error correction code used to detect and correct errors in data transmission or storage, characterized by sparse parity-check matrices

13. Natural Language Processing (NLP)

The field of study focused on the interaction between computers and human language, enabling machines to understand, interpret, and generate natural language

14. Noisy Intermediate-Scale Quantum (NISQ) Computers

Quantum computers that operate with a limited number of qubits and are prone to noise and errors, representing the current state of quantum hardware

15. NP-Hard Problem

A class of computational problems for which no efficient solution algorithm is known, and solving any NP-hard problem efficiently would solve all problems in NP efficiently

16. Pharmacodynamics

Optimization techniques used in machine learning to minimize a function by iteratively moving towards the steepest descent, adjusting parameters to reduce error

17. Pharmacokinetics

The study of how drugs are absorbed, distributed, metabolized, and excreted by the body, influencing the drug's efficacy and safety

18. Physical Qubits

The actual physical systems, such as trapped ions or superconducting circuits, used to implement qubits in a quantum computer

19. Quantum Processing Unit (QPU)

The hardware component of a quantum computer that performs quantum computations, analogous to the CPU in classical computers

20. Quantum Amplitude Estimation (QAE)

A quantum algorithm used to estimate the amplitude of a quantum state, providing quadratic speedup over classical methods for certain problems

21. Quantum Approximate Optimization Algorithm (QAOA)

A quantum algorithm designed to solve combinatorial optimization problems by approximating the optimal solution

22. Quantum Computing

A type of computing that leverages the principles of quantum mechanics, such as superposition and entanglement, to perform operations on data

23. Quantum Entanglement

A quantum phenomenon where particles become interconnected and the state of one particle instantaneously influences the state of another, regardless of distance

24. Quantum Error Correction

Techniques used to protect quantum information from errors due to decoherence and other quantum noise, enabling reliable quantum computations

25. Quantum Extreme Learning Machines (QELM)

A quantum-enhanced version of extreme learning machines, used for fast and efficient training of neural networks

26. Quantum Kernel Method

A technique in quantum machine learning that uses quantum states to represent data, enabling more efficient computation of kernel functions

27. Quantum Machine Learning (QML)

The application of quantum computing to machine learning algorithms, potentially offering enhanced capabilities for data analysis and pattern recognition

28. Quantum Neural Networks (QNNs)

A quantum algorithm designed to solve combinatorial optimization problems by approximating the optimal solution

29. Quantum Phase Estimation (QPE)

A quantum algorithm used to estimate the phase (eigenvalue) of an eigenvector of a unitary operator, with applications in various quantum algorithms

30. Quantum Reservoir Computing (QRC)

A computational framework that uses quantum systems as reservoirs to process temporal data, enhancing the performance of machine learning tasks

31. Quantum Signal Processing (QSP)

Techniques that use quantum algorithms to process and analyze signals, potentially offering improvements in speed and accuracy over classical methods

32. Quantum Transformer Models

Quantum-enhanced versions of transformer models used in natural language processing, potentially improving performance on tasks like translation and text generation

33. Quantum Variational Eigensolvers (QVE)

A hybrid quantum-classical algorithm used to find the eigenvalues and eigenvectors of large matrices, with applications in quantum chemistry and optimization

34. Qubit

The basic unit of quantum information, analogous to bits in classical computing, capable of representing both 0 and 1 simultaneously due to superposition

35. Underwriting

The process of evaluating and assessing the risk of insuring a person or asset, often used in the context of health insurance to determine coverage and premiums

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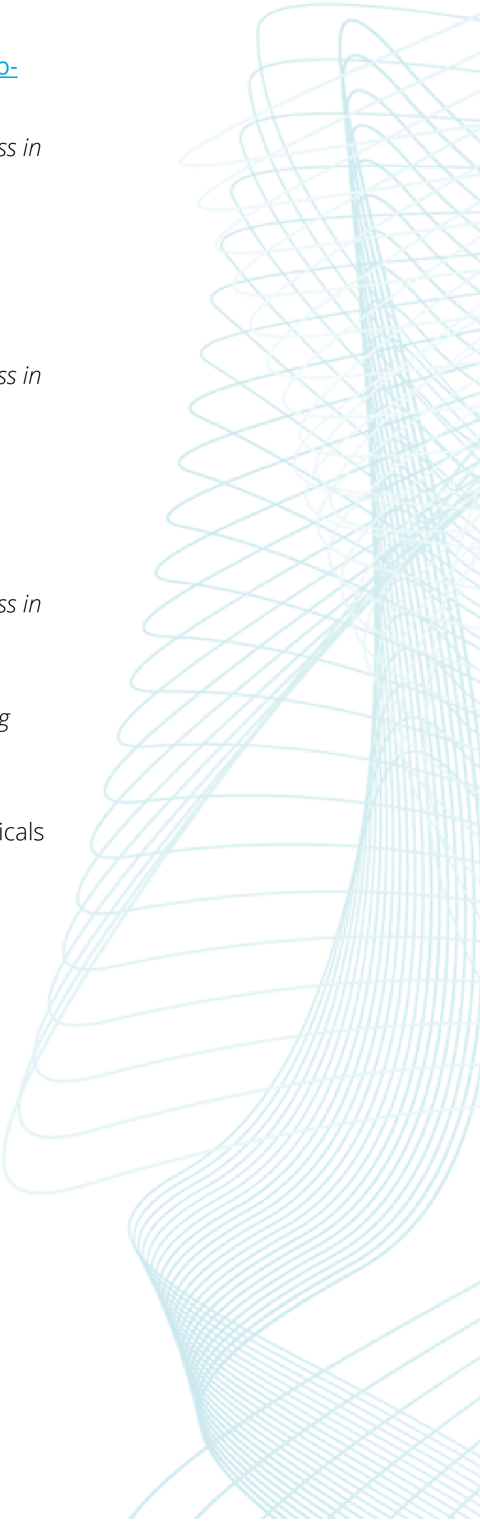

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