Research Insights

Prioritizing quantum computing applications for business advantage

Charting a path to quantum readiness

IBM **Institute for Business Value**

How IBM can help

Enterprises around the world are in various stages of assessing and experimenting with quantum computing applications for their business success. This IBM Institute for Business Value Research Insight provides an innovative quantum prioritization matrix to help these enterprises understand and select applications based on factors such as their ability to provide “quantum speed up” and “time-to-value.”

Therefore, this report is intended for quantum decision-makers, funders, designers, and programmers as well as anyone else with a deep interest in the future of quantum computing. For more information, please visit ibm.com/quantum-computing.

By Dr. Elena Yndurain and
Lynn Kesterson-Townes

Talking points

Quantum disruption

Quantum computing is likely to disrupt business operations and industry value chains. Now is the time to engage. Many initial quantum applications and algorithms will be proprietary to the individual enterprises or ecosystems that develop them.

Quantum prioritization

The path to quantum adoption requires informed decisions about which quantum computing use cases are key to specific business needs. Prioritizing these use cases is a critical undertaking.

Use case selection

Identifying a diverse mix of use cases helps prepare an organization to respond rapidly to breakthrough advances in quantum computing technology.

—

Quantum investment is accelerating

Investment in quantum technologies is booming. A veritable who's who of technology companies are developing quantum computers, custom semiconductors, and communication devices. Government investments are equally significant, ranging from USD tens of millions to billions in countries and confederations such as China, the US, Canada, the UK, the European Union, Israel, Australia, and Russia.[1]

Even though universal quantum computing has not yet reached mainstream commercialization, we predict specific applications could confer significant competitive advantage for some organizations in the coming years. Almost all organizations—90 percent according to Gartner—will be active in quantum computing projects and utilize quantum computing as a service by 2023.[2] As a result, the overall quantum computing market is forecast to reach USD 240 million by 2025, a 48 percent compound annual growth rate (CAGR).[3] Many quantum applications—even early ones—are expected to have significant disruptive implications for industries and businesses. As a result, many of today's business leaders may need to investigate the advantages of quantum computing just to preserve marketplace viability.

As quantum technology moves closer to commercialization, specific applications are emerging in areas such as chemical modeling, scenario simulation, optimization, and artificial intelligence/machine learning. For example, some quantum algorithms offer theoretical (and significant) speed-up over classical solutions, particularly for such thorny math problems as solving linear systems, searching unstructured data, conducting Monte Carlo simulations, combinatorial match, and number factorization. These algorithms are now being tested to identify the business advantages they may potentially deliver.

Rapid growth.

Through 2025, the quantum computing market is forecast to grow at an annual compound growth rate of nearly 50 percent.[4]

Earnest experimentation.

Since 2016, when IBM launched the first quantum computing cloud service, a global community of users has performed hundreds of billions of executions using quantum systems.[5]

Revenue impact.

When fault-tolerant systems are achieved in a single industry—financial services, for example—quantum computing could drive more than USD 10 billion of revenue in the first year of adoption.[6]

Getting ready for quantum computing

As quantum computers begin to become commercially viable, businesses will need to explore and assess potential applications specific to their competitive contexts. And because of their computational power and speed, some quantum applications may yield early, proprietary quantum advantage that could meaningfully affect business models or industry value chains. Because quantum is a new type of computing, early familiarity and assessment are critical for rapid adoption once the technology is ready for widespread use.

Prototype quantum systems already exist and are available to the general public at no cost. At the end of 2019, more than 200,000 users had run hundreds of billions of executions on IBM's quantum computers and simulators through the IBM Cloud. Based upon these experiments, more than 200 third-party research papers on practical quantum applications have been published.[7]

Evaluating the potential business impact of quantum computing applications can be challenging, particularly given the complexity of this emerging technology. Organizations need a way to evaluate which potential quantum computing applications are better positioned to deliver optimum business benefits for them.

A quantum computing "prioritization matrix" helps organizations address this need. Executives from various disciplines—including strategy, operations, innovation, IT, and risk—can evaluate the potential impact of quantum computing on their businesses, prioritize quantum applications, and subsequently measure quantum advantage as their organizations move from early adoption to mainstream quantum computing.

Our prioritization matrix categorizes quantum computing applications into four distinct categories:

- "Early Bloomer" applications are the most feasible to implement today
- "Late Bloomer" applications promise significant quantum advantage in the future
- "Wild Card" applications may or may not ultimately deliver clear business advantage
- "Mature Industry" applications can deliver competitive advantage on a business scale.

Insight: What is quantum computing?

"Classical" computers represent data as either a one or a zero via a bit. Quantum computers can represent data as a one or a zero, or as a combination of a one and a zero via a qubit. Qubits can be in multiple basis states at the same time, which is known as quantum superposition. Next is the peculiar phenomenon of quantum entanglement. Due to entanglement, even though two or more quantum objects may be physically separated, their behavior contains correlations that cannot be realized classically. Finally, quantum states can undergo interference to add and cancel wave amplitudes. These three quantum mechanical properties provide the potential exponential computational speed up of qubits.[8]

Insight: "Quantum advantage"

Quantum advantage is the point where, in certain cases, quantum computers can demonstrate a significant performance improvement over today's classical computers for a certain problem. "Significant" means that a quantum computation will be either hundreds—or thousands—of times faster than classical computation, will need only a fraction of the memory required by a classical computer, or can perform tasks that simply aren't possible with today's mainstream technology.

Insight: Are there quantum computing applications relevant to the advancement of your business?

To leverage quantum computing sooner rather than later, the following steps can be helpful:

- Assess your enterprise's inefficiencies that classical computers cannot currently improve, such as those associated with product development and operations. Examples include problems with complex interdependencies, such as simulating molecules for materials or drug development or constructing interdependent work schedules.
- Determine when your business is forced to employ approximations to respond to pressing market demands. Examples include problems involving complex networks such as distribution, transportation, communications, or logistics.
- Evaluate whether your organization is encountering difficulty in comprehensively computing large amounts of complex data in a timely manner. Examples include adaptive customer and vendor interactions, proactive executive decision support, targeted employee training, and other AI applications.

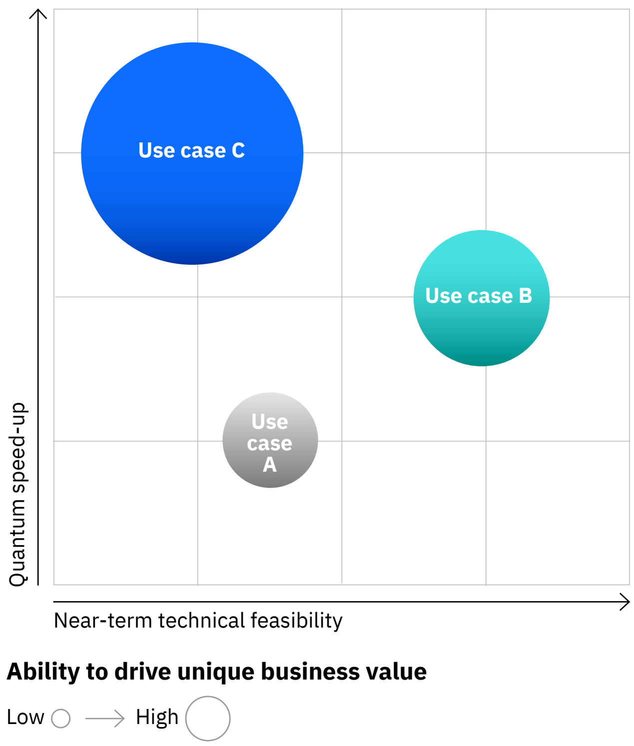
A proven prioritization framework

Our quantum prioritization matrix, illustrated in Figure 1, helps executives evaluate each application in three dimensions: 1) its theoretical capacity to deliver technological advantage over classical computing solutions (Y-axis); 2) its operational readiness (X-axis); and 3) its ability to drive unique business value for a specific enterprise (bubble size).

Prioritizing quantum applications in this way provides a complete portfolio overview, visually graphing an organization's decision trade-offs. As a result, executives can make more informed decisions about their organization's quantum adoption based on their strategic priorities, such as following a first-to-market strategy, a cost-optimization approach, or acting as an industry disruptor.

Figure 1

Quantum prioritization framework



The Y-axis: quantum speed-up

Overall, the promise of quantum advantage is to efficiently solve particular business problems that are not currently feasible (or prohibitively expensive) to resolve due to today's computational constraints.[9] Correspondingly, where an application sits on the quantum prioritization matrix's Y-axis is dependent upon the theoretical magnitude of improvement a specific quantum algorithm is expected to deliver over a classical solution. For example, quantum computing's technological advantage has already been demonstrated for two key tasks foundational for many algorithms—Fourier transforms and search.[10] As a result, applications employing these tasks are positioned higher on the Y-axis today. An individual application's quantum advantage may manifest in different ways. One example is a faster run-time to find a desired solution or a better approach to solving a problem that achieves greater accuracy.

The X-axis: near-term technical feasibility

The quantum prioritization framework's X-axis depicts the technical requirements for quantum hardware and software needed to successfully execute each identified application. A key aspect of this is the expected qubit and performance requirements. Placement on the X-axis is also impacted by further quantum hardware and software considerations, such as chip and algorithm design, qubit interconnectivity, number of gates and qubits used in the code, and the compiler's efficiency.

Bubble size: business impact

The third dimension of the quantum prioritization matrix is tailored to the size of the business impact each application is predicted to have for a specific enterprise. This dimension incorporates business metrics exclusively chosen by each organization. As part of each individual company's selection process, it is important to realize that assessing business impact is more than merely measuring economic outcomes. Metrics should be a blend of market outcomes and competitive consequences, as well as financial impact. For example, depending on an organization's strategic objectives, this dimension may include measures of value-chain enhancement, operational improvement, market disruption and/or innovation, market-share growth, revenue generation, cost reduction, and/or risk mitigation.

Determining speed-up

Several algorithms already present quantum speed-up. Quantum Amplitude Estimator (QAE) boosts the success probability in algorithms that leverage random distributions, and Quantum Support Vector Machines (QSVM) map data to larger dimensions using quantum kernels that cannot be estimated efficiently on classical machines.

Assessing technical feasibility

Even though quantum computing technologies are in a nascent state, some algorithms, such as a quantum approximate optimization algorithm (QAOA) or QSVM, have shown potential to run better on near-term quantum systems due to their shorter circuit-depth requirements, while other algorithms will need mature quantum systems to run more sophisticated problems.[11]

Business impact

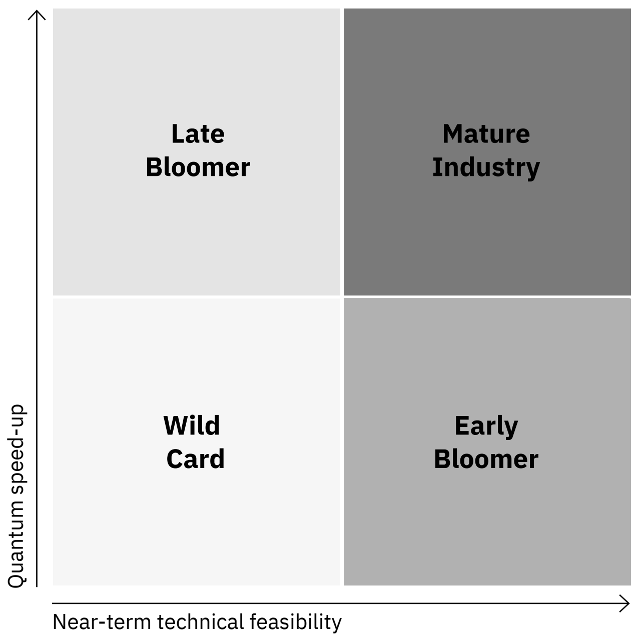
Quantum computers can transform business value chains, including mission-critical activities related to design, research, development, production, distribution, and customer targeting and engagement.

Quantum application classification

Employment of the quantum prioritization matrix elucidates four quantum application categories: “Early Bloomer” applications, “Late Bloomer” applications, “Wild Cards,” and “Mature Industry” applications (see Figure 2). Identifying a diverse mix of these types of applications prepares your organization to respond rapidly to breakthrough advances in quantum computing technology.

Figure 2

Quantum application categories



Early Bloomer

Early Bloomer applications are the “no brainers.” These are useful today for businesses to experiment with to help build talent because their solutions are heuristic. Since Early Bloomer applications operate using existing technology, their adoption is a profound step for organizations learning how to use quantum computing. The use of these types of applications helps enterprises understand how to integrate quantum computing into their current business processes and build momentum for additional quantum adoption. Adopting Early Bloomers initially may be critical to sustaining marketplace relevance, as they may establish the minimum requirements necessary to remain competitive.

Late Bloomer

Late Bloomer applications pose the “innovators dilemma.” They promise the greatest quantum advantage, but they require more advanced quantum technology to solve meaningful business problems. Late Bloomer applications can potentially transform competition in particular industries through their potential to significantly impact business value in the future. Because it is less clear when Late Bloomer applications will become technically feasible, organizations need to keep a close watch on advancements in quantum computing. A new quantum algorithm or hardware approach could cause a Late Bloomer to leapfrog into technical feasibility. Due to their expected impact on company value chains, competitive success can accrue disproportionately to those companies that are first to recognize and implement Late Bloomer quantum computing applications.

Wild Card

Wild Card applications do not currently exhibit a straight forward path to deliver the substantial quantum advantage of Late Bloomers, nor are they as technically feasible as Early Bloomer applications are today. While they may or may not ever pan out, evaluating them helps organizations better understand how quantum computing’s attributes could apply to their future success. These long shots are not to be completely counted out. As quantum technology evolves, some Wild Cards may transform into Early or Late Bloomers.

Mature Industry

Mature Industry applications are the ultimate goal for businesses leveraging quantum computing. Although no application has yet demonstrated quantum advantage at business scale, in the future—if quantum computers achieve sufficient scale and quantum applications demonstrate competitive value—some will confer business advantage, transforming company operating models and industry value chains. Some applications already in development may be placing their creators on the path to significant marketplace success even now.

Financial services institution: "Applying the quantum prioritization matrix"

To illustrate how the quantum prioritization matrix works, let's take the actual quantum application investigation undertaken by a financial services trading organization. This financial institution identified six potential uses of quantum computing that are computationally challenging for conventional machines:

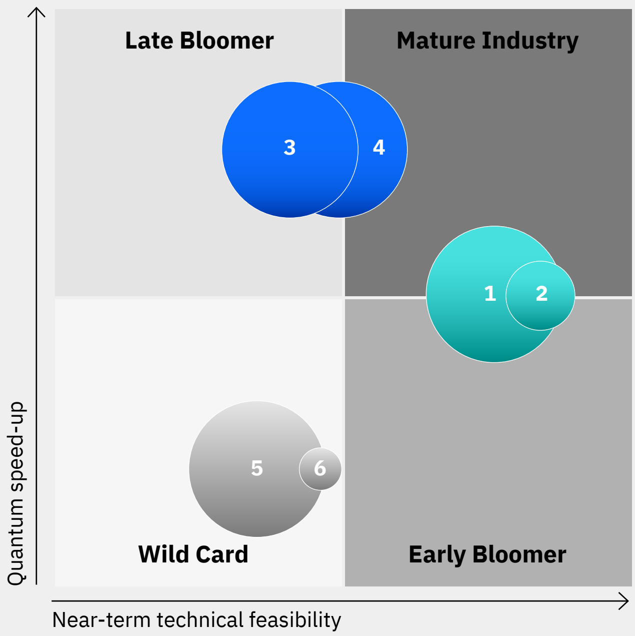
1. *Trade settlement:* Improving the process of transferring securities due to an asset trade, including reducing the time it takes.
2. *Portfolio management:* Enhancing investment decisions to optimize returns and decrease risk.
3. *Value-at-risk analysis:* Strengthening risk mitigation by developing more accurate risk-simulation models.
4. *Derivative pricing:* Improving the pricing of financial assets using market-scenario simulations.
5. *Fraud detection:* Enhancing the detection of irregular patterns to flag fraudulent transactions and imposters.
6. *Credit/asset scoring*: Strengthening the statistical analysis that segments customer financial solvency and bond ratings.

Each of these potential applications can be solved by a specific quantum computing algorithm that helps designate its level of quantum speed-up and its stage of technical feasibility (see Figure 3):

- Trade settlement and portfolio management can be solved through an optimization algorithm, QAOA. This type of algorithm brings a heuristic improved runtime and increased quality to the solution while running well on near-term quantum systems, positioning associated applications as Early Bloomers.
- Value-at-risk analysis and derivative pricing are solved with a simulation algorithm, called quantum amplitude estimation (QAE), to estimate scenarios. This type of algorithm delivers a quadratic speed-up while improving the quality of the solution. However, it requires mature quantum systems. Applications associated with this algorithm are usually identified as Late Bloomers.
- Fraud detection and credit/asset scoring are solved with machine-learning algorithms for classification and prediction (QSVM). This type of algorithm can run on near-term quantum systems and may bring increased accuracy. However, the benefit needs to be proven as quantum system capacity increases, placing associated applications typically as Wild Cards.

The business value these applications might collectively bring to the financial services industry could surpass USD 10 billion in the first year of their launch.[12] Enhancing fraud detection and reducing monetary losses from money laundering could deliver more than half of the total, with trade settlement, portfolio management, derivative pricing, risk analysis, and credit scoring making up the balance.

Figure 3
Quantum prioritization matrix applied to a financial services trading institution



Six quantum applications

1. Trade settlement
2. Portfolio management
3. Value-at-risk analysis
4. Derivative pricing
5. Fraud detection
6. Credit/asset scoring

Relevant algorithms

QAOA QAE QSVM

Action guide

Charting a path to quantum readiness

Using this methodology, we have identified five steps to developing a quantum portfolio for your organization:

1. Acquire quantum capabilities.

Identify the quantum skills your organization needs and determine whether to acquire them directly, hire a consultant, and/or join an existing quantum ecosystem to access them.

2. Identify potential quantum applications.

Select business problems or opportunities likely to benefit from the unique capabilities of quantum computing, such as those constrained by resources or by huge optimization calculations.

3. Position each application on the quantum prioritization matrix.

Evaluate the technology profile of each proposed application, both in terms of potential quantum speed-up (Y-axis) and near-term technical feasibility (X-axis) based on state-of-the-art quantum hardware and algorithms.

4. Determine the expected business impact.

Overlay the size of the projected business impact by analyzing each application's potential competitive advantage and expected financial benefits specific to your organization.

5. Plan for quantum adoption.

Determine whether you will purchase a quantum computer or access the latest quantum technology through a partnership arrangement. Plan for quantum's impact on your internal workflows, including potential process redesign and resource allocation adjustments.

About the authors

Dr. Elena Yndurain
linkedin.com/in/elenayndurain/
Elena.Yndurain@ibm.com
@yndurain
www.yndurain.com

Dr. Elena Yndurain leads financial services within the IBM Q consulting team helping clients get ready for quantum computing.

Lynn Kesterson-Townes
linkedin.com/in/lynnkesterson/
lkt@us.ibm.com
@LynnKesterson

Lynn Kesterson-Townes is Global Cloud and Quantum Computing Leader at the IBM Institute for Business Value.

The right partner for a changing world

At IBM, we collaborate with our clients, bringing together business insight, advanced research, and technology to give them a distinct advantage in today's rapidly changing environment.

IBM Institute for Business Value

The IBM Institute for Business Value, part of IBM Services, develops fact-based, strategic insights for senior business executives on critical public and private sector issues.

For more information

To learn more about this study or the IBM Institute for Business Value, please contact us at iibv@us.ibm.com. Follow @IBMIBV on Twitter, and, for a full catalog of our research or to subscribe to our monthly newsletter, visit: ibm.com/ibv.

Notes and sources

1 Deagon, Brian. "Quantum Computing Companies Aim To Go Where No Computer Has Gone Before." Investor's Business Daily. February 2019. https://www.investors.com/news/technology/quantum-computing-companies-aim-technology-higher/

2 Brisse, Matthew. "The CIO's guide to quantum computing." Tech Radar Pro. September 06, 2019. https://www.techradar.com/news/the-cios-guide-to-quantum-computing

3 "Quantum technologies: a jump to a commercial state." Yole Développement. February 2020. https://s3.i-micronews.com/uploads/2020/01/YDR20062-Quantum-Technologies-2020-Yole-Développement-Sample.pdf

4 Dr. Mounier, Eric. "Quantum technologies: a jump to a commercial state." Yole Développement. February 2020. https://s3.i-micronews.com/uploads/2020/01/YDR20062-Quantum-Technologies-2020-Yole-Développement-Sample.pdf

5 "IBM Working with Over 100 Organizations to Advance Practical Quantum Computing." IBM. January 2020. https://newsroom.ibm.com/2020-01-08-IBM-Working-with-Over-100-Organizations-to-Advance-Practical-Quantum-Computing-Signs-New-Collaborations-with-Anthem-Delta-Airlines-Goldman-Sachs-Wells-Fargo-Woodside-Energy-Los-alamos-National-Laboratory-Stanford-University-Georgia-Tech-and-Sta

6 "Exploring quantum computing use cases for financial services." IBM Institute for Business Value. September2019. https://www.ibm.com/thought-leadership/institute-business-value/report/exploring-quantum-financial

7 "IBM Working with Over 100 Organizations to Advance Practical Quantum Computing." IBM. January 2020. https://newsroom.ibm.com/2020-01-08-IBM-Working-with-Over-100-Organizations-to-Advance-Practical-Quantum-Computing-Signs-New-Collaborations-with-Anthem-Delta-Airlines-Goldman-Sachs-Wells-Fargo-Woodside-Energy-Los-alamos-National-Laboratory-Stanford-University-Georgia-Tech-and-Sta

8 "Part One: Quantum Properties." IBM. Accessed January 2020. https://www.ibm.com/quantum-computing/learn/what-is-quantum-computing/

9 Sutor, Bob. "Scientists Prove a Quantum Computing Advantage over Classical." IBM. October 2018. https://www.ibm.com/blogs/research/2018/10/quantum-advantage-2/

10 Nielsen, Michael, Isaac Chuang. "Computation and Quantum Information – 10th Anniversary Edition." Cambridge University Press. 2011. ISBN 978-1-107-00217-3 2010.

11 Moll, Nikolaj, Panagiotis Barkoutsos, Lev S. Bishop, Jerry M. Chow, Andrew Cros, Daniel J. Egger, Stefan Filipp, Andreas Fuhrer, Jay M. Gambetta, Marc Ganzhorn, Abhinav Kandala, Antonio Mezzacapo, Peter Müller, Walter Riess, Gian Salis, John Smolin, Ivano Tavernelli and Kristan Temme. "Quantum optimization using variational algorithms on near-term quantum devices." Quantum and Science Technology. June 2018. https://iopscience.iop.org/article/10.1088/2058-9565/aab822; Havlicek, Vojtech, Antonio D. Córcoles, Kristan Temme, Aram W. Harrow, Jerry M. Chow, Jay M. Gambetta. "Supervised learning with quantum-enhanced feature spaces." Nature. 2019. https://arxiv.org/pdf/1804.11326.pdf

12 "Exploring quantum computing use cases for financial services." IBM Institute for Business Value. September 2019. https://www.ibm.com/thought-leadership/institute-business-value/report/exploring-quantum-financial

About Research Insights

Research insights are fact-based strategic insights for business executives on critical public and private sector issues. They are based on findings from analysis of our own primary research studies. For more information, contact the IBM Institute for Business Value at iibv@us.ibm.com.

IBM Corporation
New Orchard Road
Armonk, NY 10504
Produced in the United States of America
June 2020

90032390USEN-00