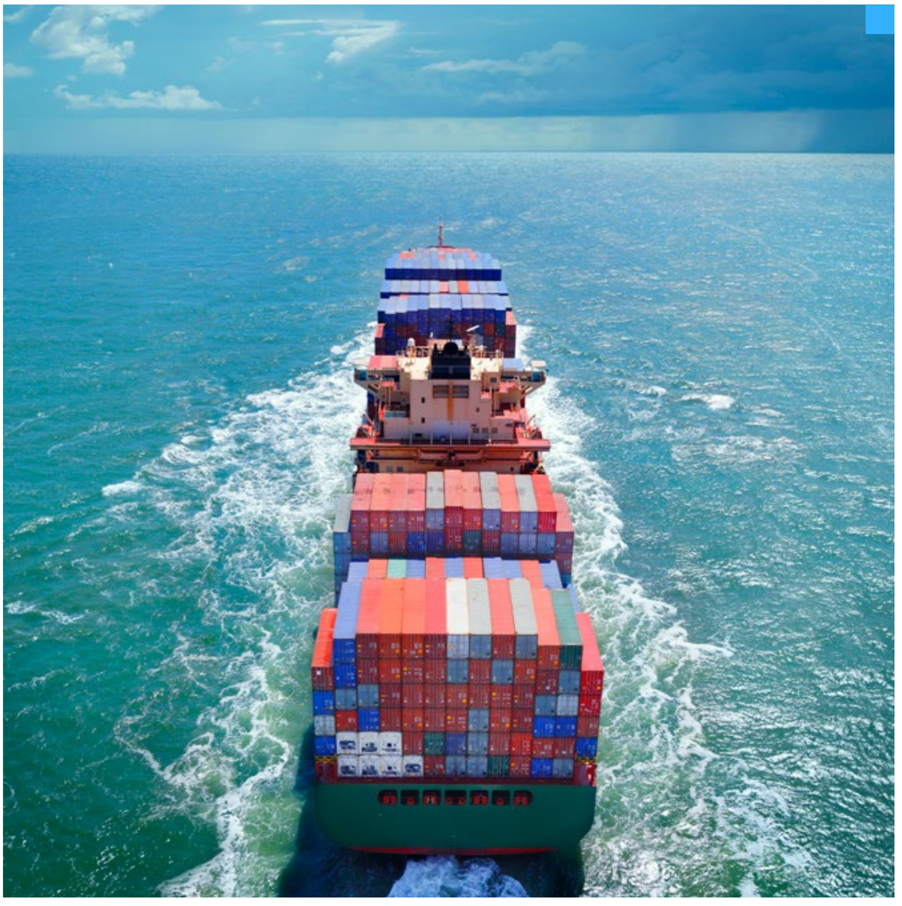

Exploring quantum computing use cases for logistics

Navigate last mile delivery, disruption, and maritime routing

IBM

Foreword

Transportation has been in the spotlight lately. But rather than a warm glow, it's been a bit scorching. Global supply chain issues have inflamed politicians, vexed retailers, and frustrated consumers more in the past few years than ever before.

Unfortunately, while the industry's few stumbles are endlessly discussed, its many triumphs are drowned out by voices calling for supply chain improvements, ever greater efficiency, and lower carbon emissions. Perhaps the most exciting—yet unnoticed—development in the industry is the slow but significant advancement (and increasing relevance) of quantum computing solutions for the transportation industry. This new technology gives hope to an industry that continues to deliver the essentials of life to the world, despite challenging conditions.

Despite unending ideas on how to fix the challenges of increasingly complex and interdependent supply chains, few experts have identified the root of the challenges: coordination.

The scope, size, and complexity of supply chains have resulted in network-scale challenges. Network effects multiply the impacts of constraints and delays. Adding a geopolitical crisis, a run-of-the-mill supply shock, or a local drought, to this already strained system of systems can create instant, lasting disruptions.

The solution to this complex and interdependent system-of-systems challenge requires a broader perspective. Silo-based, function-based, or even enterprise-wide optimizations no longer provide the cure. Instead, the industry needs optimizations that account for the full complexity of the entire ecosystem. Doing so requires a level of coordination among partners, governments, and shippers that current optimization solutions—using classical computing—cannot provide to the levels necessary.

The maturation and development of quantum computing, however, could change this equation significantly. If individual transportation providers, regulators, and customers can better share insights and collaborate to optimize operational decisions, quantum computers could produce better overall outcomes for the entire supply chain, and for humanity.

Please take a moment to read and consider our perspective on the applicability of quantum computing solutions to the transportation industry. I invite you to share your views of support or dissension with members of your own network because—like most other aspects of the future of our industry—the problems worth solving are the ones that require us to start with a shared vision of the future.

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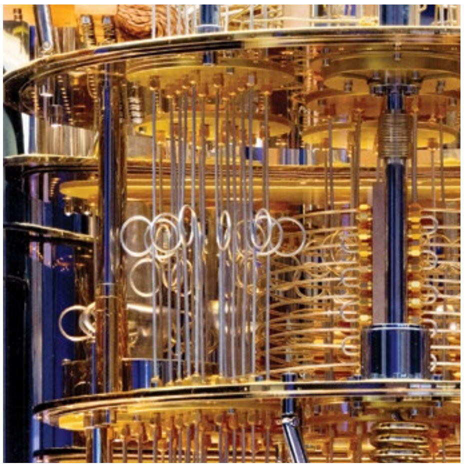


Executive summary

The industry needs optimizations that account for the full complexity of the ecosystem.

Quantum algorithms for last mile delivery? Game-changing potential.

Even a 1% performance improvement in last mile delivery could lead to an annual $400 million in savings worldwide.[1] Using quantum algorithms for better fleet management and more profitable delivery has game-changing potential to significantly reduce door-to-door freight transportation costs, as well as boost customer satisfaction.

Quantum-enabled disruption management can put uncertainty on notice.

Pandemics, wars, natural disasters, and more mandate that transportation and logistics professionals manage disruption better. Supply chain disruptions are an economic hardship, costing organizations around the world an average of $184 million per year.[2] Quantum computing can support better decision-making by simulating more disruption scenarios than classical systems and quantifying their impact on various parts of the network.

A quantum leap for sustainable maritime routing.

90% of the world's trade volume travels by sea.[3] Yet, in an increasingly expensive proposition, 1 in 3 shipping containers is moved while empty due to global trade imbalances. Quantum algorithms may enable more accurate modeling for streamlined, sustainable maritime operations.

Routing the future with quantum computing

In the age of globalization and international trade, effectively managing transportation and logistics is vital to the health of the economy and society in general. As events surrounding the COVID-19 pandemic illustrate, logistical disruptions can have catastrophic impacts on both business-to-business operations and consumer behavior. In today's interconnected digitized world, logistics and supply chain strategies are perhaps more important than ever—and more complex.

Before the pandemic, the average consumer didn't think much about how the products they used or foods they ate were transported—they just took it for granted that everything they wanted was already available. Now, "supply chain" is common vernacular and stories of disruption dominate news cycles as capacity shortages, rising transport costs, and the acceleration of online commerce continue to pose challenges.

Scaled challenges require a new kind of computing power

The overall goal of a logistics enterprise is optimized operations at all times—a tall order that is easier said than done. Even during times of more stability, logistics management is a complex discipline, involving a network of moving parts and systems ranging from logistics planning, to manufacturing and supply, storage and distribution, and transportation/shipping.

Organizations rely on logistics optimization models to help them reduce overall costs while satisfying capacity constraints and meeting demand through effective procurement, production, storage, distribution, and transportation. And the more information involved in the logistics equation, the better. More information, however, also means more complex models that require exponential increases in computing power. Today's logistics providers are facing complexities that push the limits of their technologies. At scale, these problems are challenging to solve with only classical computing technologies.

Quantum: Fit for purpose

Quantum computing could offer a solution. A fundamentally new computing paradigm, quantum computing leverages phenomena that simply do not exist in classical physics—which, in turn, may enable computation that hasn't been possible to date (see "Perspective: The basics of quantum computing"). Quantum computing could evolve into a powerful tool to help tackle some of today's biggest challenges related to transportation and logistics.

Just as IBM has been innovating chip technology for decades, we have also been at the forefront of quantum computing.[4] In 1981, IBM cohosted the first conference on quantum computing.[5] In 2016, IBM was the first to make quantum computers publicly available.[6]

By providing access to quantum computers, IBM has enabled researchers and developers around the world to innovate new quantum algorithms and accelerate advances in quantum computing. We are now in the Quantum Decade.[7] With IBM's quantum computing roadmap, organizations can plan for the technology's future capabilities (see Figure 1 on page 6).[8]

The principle of superposition allows a quantum computer to represent and compute on multiple states simultaneously.

Perspective

The basics of quantum computing

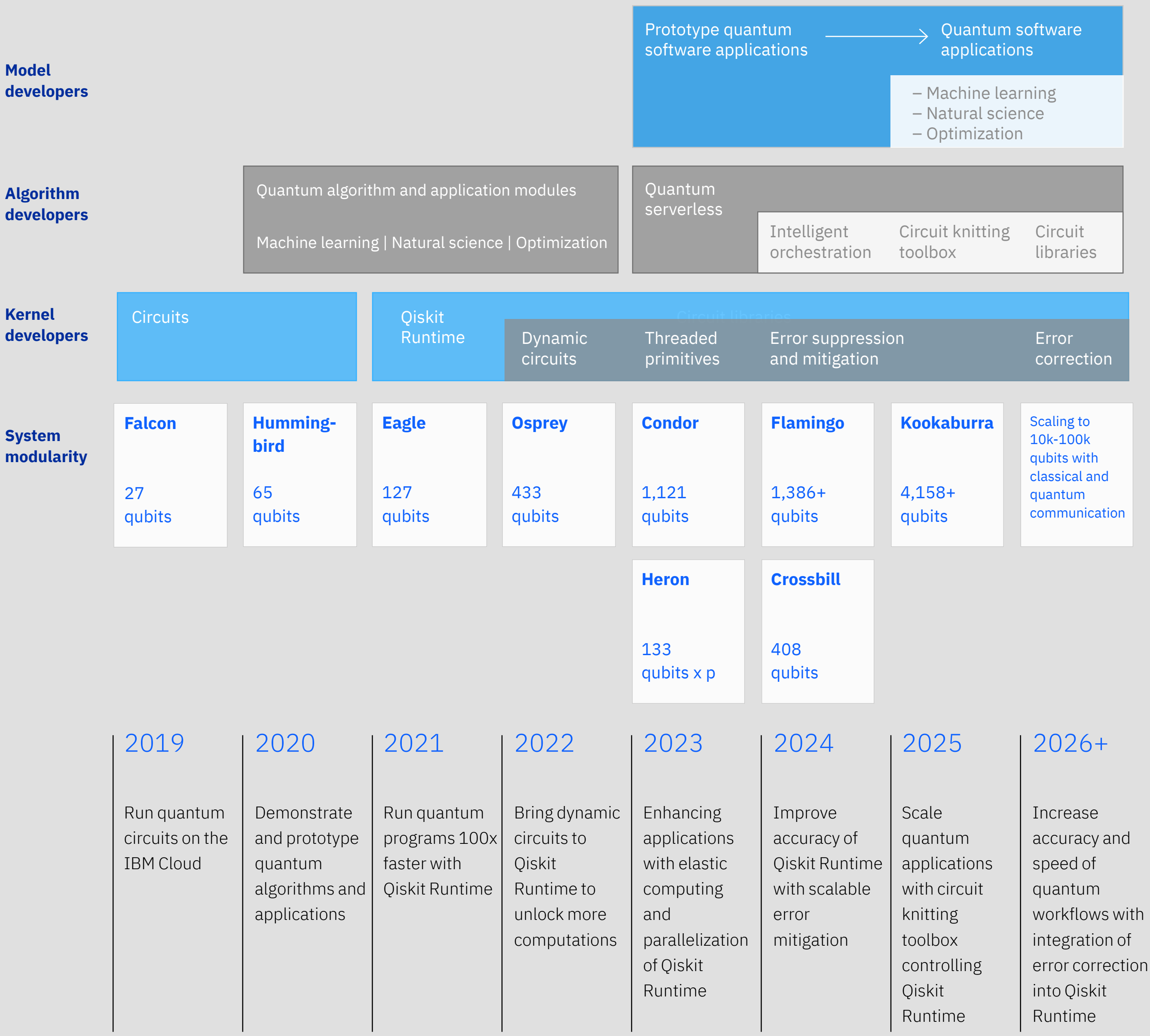
Classical computers store information bits coded as either a 0 or 1. But as scientists were able to explore subatomic matter, they began to see very different behavior, such as particles that could behave as both—in two locations at the same time (superposition) and pairs of particles mysteriously linked no matter how far apart they were (entanglement). The field of quantum physics emerged to explore and understand these phenomena.

The principle of superposition allows a quantum computer to represent and compute on multiple states simultaneously. Entanglement means the combined state of the quantum bits (qubits) contains more information than each of the qubits do independently.

FIGURE 1

The IBM quantum computing roadmap

Recent progress and looking ahead



Although quantum computing technologies are still in a nascent state, they show promise in solving global logistics optimization models. Doing so with practically significant accuracy will require still-to-come, advanced, error-corrected quantum computers with very large numbers of qubits. However, even not-so-distant small computational gains could translate to cost savings and improved customer service in the near term.

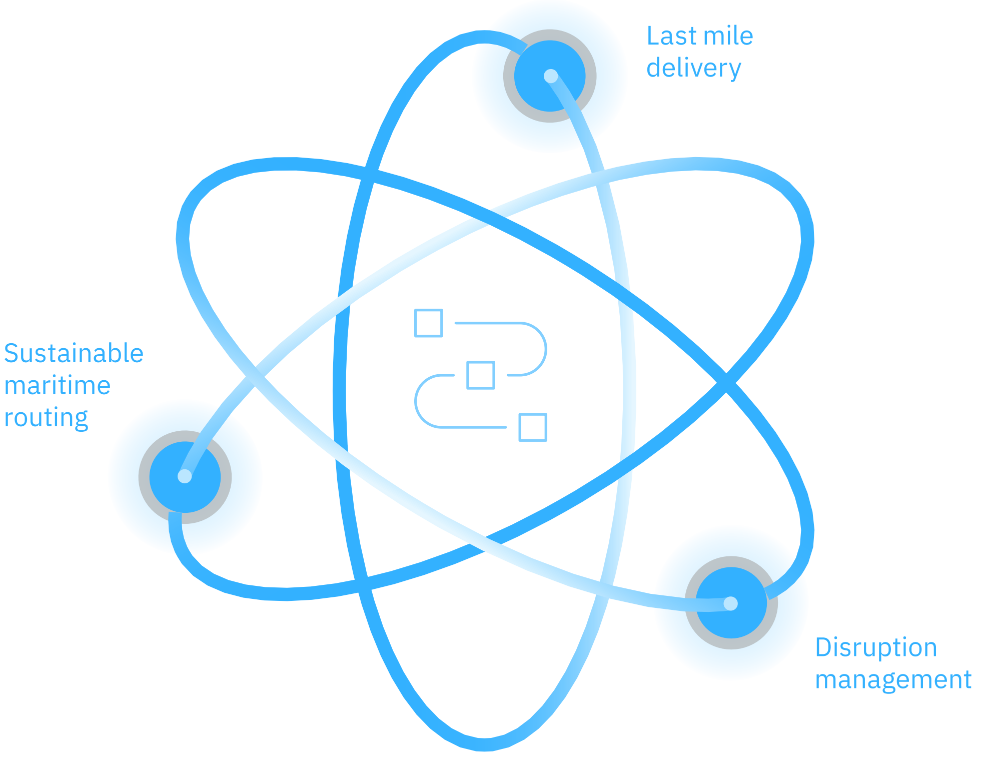
3 logistics use cases for quantum computing

In transportation and logistics, as in other industries, pairing quantum computing capabilities with classical computers could help organizations address a number of critical logistics challenges. In this report, we explore three potential use cases (see Figure 2):

1. *Last mile delivery:* Improve last mile delivery with quantum-enabled optimization models.
2. *Disruption management:* Improve decision-making and recovery times with faster, more accurate simulations.
3. *Sustainable maritime routing:* Reduce inefficiencies and port congestion with more accurate optimization techniques.

FIGURE 2

Quantum computing use cases for logistics



Use case 1

Last mile delivery

As customer expectations for speedy omnichannel fulfillment continue to increase, optimization of multimodal transportation, particularly the last mile, is a must. One of the hottest topics in global logistics, last mile delivery represents an enormous competitive opportunity, buoyed by the meteoric growth of ecommerce. Valued at $40.7 billion in 2022, the last-mile-delivery market is projected to grow to $86.2 billion by 2032.[9]

Arguably the most expensive and challenging step of the supply chain, last mile delivery has only gotten trickier amidst current disruption. The pandemic further propelled the rise of ecommerce. Shifting consumption habits and unpredictable demands are increasingly commonplace. The ability to pivot quickly is crucial to meet consumer delivery expectations. However, current systems remain fragmented and static, able to conduct only limited optimizations for large scale logistics networks.

To highlight the scale and complexities involved, consider that in 2020, the global daily average delivery volume for UPS was already almost 25 million packages and documents.[10] Optimization models of this size push the limits of classical computing and, at the same time, point toward opportunities for quantum computing.

Classical last mile delivery solutions are based on heuristics and have limited inputs. Responding to frequent changes and demand shifts is difficult and slow. The state space of many last mile delivery optimization problems grows exponentially in complexity with the size of the input. This leads to solutions with high optimality gaps (the gap between an approximate solution and the optimal solution) and long run times—and illustrates the limitations of classical computing.

Research indicates quantum algorithms have the potential to solve larger, more complex logistics problems.[11] These algorithms could support more efficient searches of the solutions landscape, opening the door to discovery of more profitable delivery routes and better fleet management.

By supporting global routing optimization and more frequent re-optimization, quantum computers could help significantly reduce door-to-door freight transportation costs, as well as boost customer satisfaction. Progress in last mile delivery could be game-changing for the logistics industry: Even a 1% performance improvement could lead to an annual $400 million in savings worldwide.[12]

Perspective

Taking last mile delivery to the next level while reducing costs

In 2020, global parcel shipping volume amounted to over 131 billion parcels.[13] By 2026, this volume is expected to more than double to 266 billion parcels.[14] The sheer volume of packages shipped has contributed to large-scale routing problems that are testing the precision and speed of classical computers.

IBM worked with a commercial vehicle manufacturer to show how a mix of classical and quantum computing could optimize delivery to 1,200 locations in New York City. Using a route-based approach, the team factored in the need for 30-minute delivery time windows, while recognizing truck capacity constraints—all while reducing the total cost of delivery.

First, in a classical step, the team applied machine learning and optimization techniques to generate a set of route options. Then they applied quantum algorithms to investigate and refine a subset of optimal routes.

The experiment resulted in four key takeaways that our teams plan to use in future experiments:

1. It's important to use real-world problems to understand the nuances of quantum applications. Actual instance-based customization of problem mappings and assumptions may improve the solutions.
2. Explore out-of-the-box approaches to using classical and quantum, because frequently used approaches for classical computation are not always appropriate.
3. Classical skills are key to taking advantage of quantum computing, but you need to understand the limitations of classical computing and how to best integrate with quantum computing.
4. Carefully outline the objectives of the experiment to manage expectations. The goal is to understand how classical and quantum computing can work together, essentially creating a baseline for continuous experimentation.

Use case 2

Disruption management

While the COVID-19 pandemic delivered a violent shock to global supply chains, it represented but one in a long history—and it certainly will not be the last. The ability to rapidly and efficiently respond to and manage disruptive events will remain critical for logistics enterprises.

Leaders are responding to disruption by building intelligence and agility into their supply chains, in a quest for radically improved performance and resilience. Data-led solutions are key to this shift; 73% of leaders say they recognize the strategic value of data and 64% are using data to identify new opportunities.[15]

The ability to more accurately simulate the impacts of logistics disruptions is crucial, leading to more rapid responses and shorter recovery times. However, the complexities of managing international fleets of planes, trains, ships, and trucks and serving millions of businesses and consumers stretch the limits of current disruption management systems.

Classical systems are mainly rule-based, consisting of manual and ad hoc processes. Siloed and sequential, they provide limited insight for supporting flawless recovery decisions. They deal with personnel, equipment, and materials separately in a suboptimal manner. System-wide recovery can take anywhere from a week to more than two months. In addition, complex environments with numerous elements and dependencies can generate an enormous number of disruption scenarios. However, current simulations typically try to find only the most feasible scenarios rather than considering all of the components.

Quantum computing could support better decision-making by simulating more disruption scenarios and quantifying their impact on various parts of the network. Quantum computers performing risk and impact analysis may be able to reduce the number of “what if” simulation scenarios necessary to achieve conversion to the best result within actionable time windows. This could help improve recovery times, lower costs, and lessen operational and customer service impacts.
In addition, quantum machine learning may enable more precise classification and prediction of disruption events.

Improvements in disruption management could be transformational for transportation and logistics, as well as help reduce the $184 million, on average, lost globally due to supply chain disruptions.[16]

Perspective

Quantum Advantage

Quantum Advantage occurs when a computing task of interest to business or science can be performed more efficiently, more cost effectively, or with better quality using quantum computers. This is the point where quantum computers plus classical systems can do significantly better than classical systems alone. As hardware, software, and algorithmic advancements in quantum computing coalesce, enabling significant performance improvement over classical computing, new opportunities for advantage will emerge across industries. But prioritizing the right use cases—those that can truly transform an organization or an industry—is critical to attaining business value from quantum computing.

Organizations that enhance their classical computing capabilities and aggressively explore the potential for industry transformation now, by investigating and investing in quantum exploration, will be best positioned to seize Quantum Advantage.[17]

Use case 3

Sustainable maritime routing

With 90% of the world's trade volume traveling by sea,[18] optimizing container shipping is an essential priority for maritime logistics. Elevated shipping rates over the past two years made global container shipping a $150 billion market.[19] Due to imbalances in global trade, many containers are shipped empty, a practice that is becoming increasingly expensive. For example, shipping a 40-foot container from Asia to Europe costs between $15,000 and $20,000, compared with $2,000 in 2019.[20]

The classical approach to container shipping operations is a mix of human intuition and ad-hoc optimization solutions. Although simulation modeling is employed at some ports and terminals, solutions are often local and use limited data inputs. Due to a lack of data insights, many container shipping decisions are made based on "instinct."

With contingencies that include large fleets and uncertainties such as weather and demand fluctuations, many optimization challenges in shipping operations can't be precisely solved exactly using classical computers. Producing a useful solution, even for a small-scale problem, takes many hours.[21]

However, quantum algorithms may enable more accurate modeling. More precise demand forecasting and better inventory routing on a global scale could enable more streamlined—and sustainable—maritime operations.[22] In addition to addressing societal demands for improved air quality and reduced carbon emissions, container repositioning improvements could save millions of dollars a year.[23]

ExxonMobil models maritime inventory routing on quantum devices[24]

$2^{1,000,000}$

Number of combinations of decisions in a global LNG shipping network

2^{270}

Number of atoms that exist in the universe

ExxonMobil has invested $10 billion since 2000 to develop lower emission energy solutions.[25] As it continues to reduce environmental impacts, natural gas is in the mix more and more.

Shipping liquefied natural gas (LNG), though, is unlike shipping many materials. LNG must be shipped "just in time" due to its limited shelf life. Efficient shipping is critical.

In 2021, more than 500 LNG ships transported critical fuel supplies across the oceans. Together, they make thousands of journeys per year to destination ports where the LNG powers critical infrastructure.

Finding optimal routes for a fleet of such ships can be a mind-bendingly complex optimization problem. To efficiently transport LNG, each ship's position must be accounted for on each day of the year, along with the LNG requirements of each delivery site. The number of possibilities make it a difficult scenario to optimize when using classical computing, based on the sheer number of decision combinations in a global LNG shipping network—it's greater than the total number of atoms in the universe.

Scale up the problem to a larger fleet, or introduce uncertainties such as weather, and a problem this size rapidly becomes intractable—running up against the hard limits inherent to even the most advanced classical computing systems.

Quantum computers take a new approach to addressing this sort of complexity, with the potential to find solutions that classical supercomputers alone cannot handle. Industry leaders such as ExxonMobil are getting involved to explore how blending classical and quantum computing techniques might solve big, complex, pressing global challenges.

Teams at IBM Research and ExxonMobil Corporate Strategy Research have collaborated to model maritime inventory routing on quantum devices, analyzing the strengths and trade-offs of different strategies for vehicle and inventory routing, and laying the foundation for constructing practical solutions for their operations.

As IBM's quantum hardware scales rapidly—from small prototype systems to more promising larger devices—researchers are excited about the possibility to one day handle previously insoluble routing problems.

"By partnering with IBM Quantum, our aim is to ultimately level-up our ability to tackle more complex optimizations," says ExxonMobil's Dr. Vijay Swarup, vice president of research and development. "To solve bigger problems and make bigger differences."

Action guide

Exploring quantum computing use cases for logistics

Quantum computing holds the potential to deeply impact global transportation and logistics. Indeed, research suggests organizations in the transportation and logistics arena are among those with the most to gain from quantum computing's groundbreaking capabilities.[26]

An organization's path from initial investigation of quantum computing to actual readiness for implementation can span a few years—or more. In business, this can be akin to a lifetime.

A wait-and-see approach could mean the difference between being disrupted and being the disruptor. That's why it's important to begin building quantum readiness sooner rather than later. Below are some steps you can take today:

Develop internal expertise so you can make informed decisions

Because the learning curve for quantum computing is steep and quantum computing skills are scarce, much of the expertise may need to be developed in house. Identify and upskill both technical and business talent inside your organization in forming your quantum computing team. Build capabilities around this technology that align with your organization's objectives and constraints.

Identify your most critical and compelling use cases

Highlight the ways your organization could not only benefit from quantum computing but also be threatened by it. Look at the three use cases we discussed and examine other potential uses for your particular organization. Once you've identified use cases, you can then estimate the time pressure to act.

Translate your use cases into proofs of concept, providing the opportunity to explore quantum computing and learn how it fits into your strategies

Partner with quantum computing experts to develop prototypes. Obtain access to the quantum computing hardware and software platforms you'll need. Experiment with quantum computing code in a scalable fashion so that when quantum computers are ready, so is your code.

Rethink your core workflows.

Identify the steps in your workflows that might benefit from Quantum Advantage. Understand how quantum and classical workflows and dataflows can intersect. Learn how quantum and classical computing can be combined to leverage each other. And employ design thinking to help you examine your end-to-end processes so you can make the most of quantum computing's potential.

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