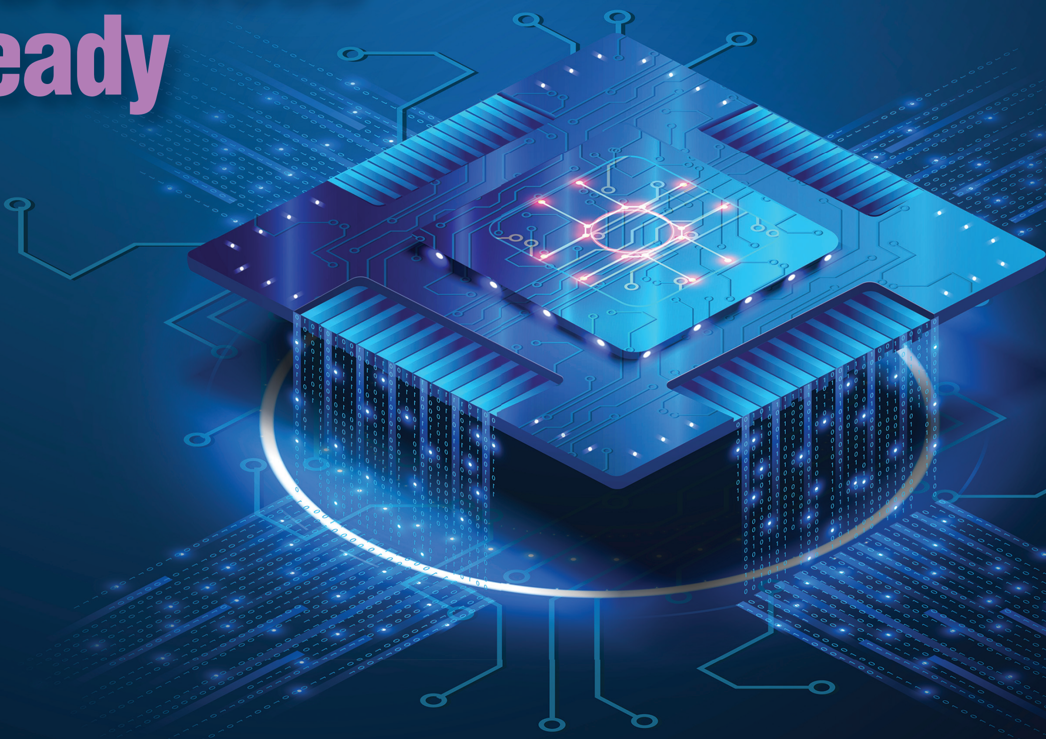
Make Your Business Quantum-Ready Today



ManMohan S. Sodhi
Bayes Business School, City, University of London

Sridhar R. Tayur
Tepper School of Business, Carnegie Mellon University

©shutterstock.com/ZinetroN

How can executives capitalize on the promise of quantum computing for their businesses? ManMohan Sodhi and Sridhar Tayur suggest a low-risk approach using quantum-inspired computing.

The history of the computer precedes the first programmable digital computer, the 1946 ENIAC.[1] During WWII, a 'computer' was a person employed to, well, compute. In the 20th century, quantum mechanics brought on the *first quantum revolution*, transforming computation with the invention of the transistor and the integrated circuit unit (ICU) which is currently used in a vast range of computers, from handheld devices to supercomputers.

Now, in the 2020s, we are on the cusp of a *second quantum revolution*, spurred by the reimagined use of quantum mechanics[2] in concert with computer science[3] and information theory.[4] Business leaders have the chance to be the co-creators of this new future. Quantum computing is becoming ever more visible, not just in research journals, but in articles published by mainstream business journals.[5,6] Indeed, many managers already feel compelled to get involved, simply because application providers have argued persuasively that the payoff will be immense.[7]

Quantum computing was first proposed by Paul Benioff,[8] Yuri Manin,[9] and Richard Feynman[10] as a means of overcoming the limitations of digital computing by emulating nature. Quantum computing discards the binary (0/1) bits of digital technology, in favor of qubits that can take many different states simultaneously, making computing, say, complex combinatorial problems much faster. Moreover, many problems, like simulating materials at the molecular level, can be solved only by computing with qubits. So, as well as offering fast computation, which could drastically reduce solution times for practical-sized combinatorial problems,[11] quantum computing is also expected to solve simulation problems at the molecular or atomic level that would otherwise be unsolvable.

Still, while this frontier of computing promises treasure, it is also highly uncertain[12] when, and indeed if, quantum computing will become widely available for mainstream business applications. Many tech giants and well-funded startups are working on a range of ideas for quantum computers, but commercial models might not become available until the late 2020s or early 2030s. Furthermore, many quantum computer architectures require temperatures near absolute zero (0.15 K or below), which makes them energy hogs.

Senior managers thus find themselves on the horns of a dilemma. They can wait for the technology to mature and risk falling behind, or they can invest in quantum computing immediately and risk frittering resources away on a wild goose chase, with returns on their investment nowhere in sight.

> Executives do have a way out of this dilemma: they can invest in quantum-*inspired* computing today.

However, executives do have a way out of this dilemma: they can invest in quantum-*inspired* computing today. This service is already available via the cloud on digital computers such as Fujitsu's Digital Annealer and Toshiba's Simulated Bifurcation Machine (SBM). Quantum-inspired computing uses digital computers with specially designed architecture to calculate quantum-formulated problems. Quantum-inspired computing thus comprises two steps which would also be used for actual quantum computing: formulating the problem for quantum computing, and using an algorithm rooted in the principles of quantum mechanics to solve that problem. Only the third step, using digital computers with a specialized architecture to optimize the algorithm, differs.

Because the first two steps will also be used for (true) quantum computing, any investment in quantum-inspired computing is also an investment in quantum computing, whenever it should become practical and accessible. The effort would not be invested in a science project which might lead nowhere. And in the case of some architectures and business applications, there are immediate computational gains.

By understanding the business applications of the quantum computing that providers and users are now developing, managers can scan the computing ecosystem to find how it will be useful to their firms. Executives should take stock of their companies' advanced computing needs to determine whether quantum applications suit their business requirements. With this knowledge they can get their organizations quantum-ready now by adopting the quantum-inspired computing that is already available.

Find Applications and Providers for Quantum Computing

There are several types of quantum architecture (Table 1). *Quantum computing* is split into two main categories: quantum annealing, being advanced by D-Wave and Honeywell, and gate (circuit) model systems, being developed by Google, IBM, IonQ, and Rigetti. However, *quantum-inspired computing* is a fundamentally different approach. It uses hardware from Hitachi, Fujitsu, and Toshiba and is available today for business applications. Amazon Braket, meanwhile, has begun to provide access to simulators and a variety of experimental hardware from startups D-Wave, IonQ, OQC, Rigetti, and Xanadu, in addition to quantum-inspired hardware by Toshiba's SBM.

> Managers should focus on the business applications and not worry about architectures.

At this early stage of quantum computing development, executives should certainly not be surprised that many different approaches are under development. Managers, however, should focus on business applications[13] and not worry about architectures.

As the sampling of applications in Table 2 suggests, many sectors may gain from quantum computing's ability to solve complex combinatorial problems and run huge numbers of simulations. Some applications for designing

Table 1: Companies offering quantum computing

Quantum computing		Quantum-inspired computing
Adiabatic quantum computing (including quantum annealing)	Gate-based quantum computing	
D-Wave Honeywell	Google IBM IonQ Rigetti	Hitachi Fujitsu Toshiba

Table 2: A sample of business applications for some sectors

Sector	Application	Examples of companies
Aerospace and Defense	Materials, component design Defense and security	Lockheed, Airbus, Boeing
Automotive	Materials, component design Automated vehicle design	Volkswagen, Diamler, Toyota, BMW, Denso
Chemicals	Computational fluid dynamics Designing new materials Designing new batteries Logistics and supply chain	Exxon Mobil, Mitsubishi Chemicals
Finance	AI/Machine learning for fraud detection Pricing of derivatives Portfolio optimization Monte-Carlo simulation of risk	Goldman, JP Morgan Chase, BBVA, Bankia
Pharmaceutical	Drug discovery	GSK, Astex Pharmaceuticals

new materials or products for the aerospace, automotive, and pharmaceutical industries have to create and evaluate billions and trillions of combinations. Many industries, and particularly health-care, are already benefitting from artificial intelligence and machine learning. Quantum computing will help with the computationally intensive training phase of such applications. In the pricing and design of instruments in finance and insurance sectors, running parallel simulations is essential, so those sectors should also be keen to develop quantum applications that might solve such problems in seconds rather than days. Finance firms also benefit from parallel evaluation of combinations to find optimal portfolios.

Define Your Need for Advanced Computing

Managers should evaluate how, and if, quantum computing fits their organizations. You can identify possible applications by examining which of your current applications are computing-intensive, where you have computing bottlenecks, and which computational and data functions are done in-house and which are outsourced.

Identify current applications that are computing-intensive

You may be quite familiar with the enterprise systems, like ERP (enterprise resource planning) or CRM (customer relationship management), that your organization uses. To find all your computing-intensive systems, though, you will probably need to dig deeper, examining function-specific applications used by R&D, manufacturing, or risk management. The sampling of applications presented in Table 2 may give you some sense of what to look for in your organization.

If digital computers become two times or even ten times as fast, the productivity of these applications will improve while using the same data sources and the same personnel. Indeed, with graphics processing units (GPU) and cloud elasticity you can get a two to ten times parallel speedup right now, albeit at a proportional two to ten times higher cost.

Identify future applications if computing were not a bottleneck

If computing became a hundred or a thousand times faster at the same cost and energy usage, what applications could (and would) you use? You have already identified the applications your organization is already using; now consider what you are *not* doing because of computing bottlenecks.

Just as an airplane is not just a faster car, quantum computing is not just a faster desktop or workstation.

Just as an airplane is not just a faster car, quantum computing is not just a faster desktop or workstation. Quantum computing will reveal new vistas, so now is the time to consider applications you are not currently using or developing, but that may become possible with quantum computing. Current machine learning in science and engineering has problems with pattern recognition that are outside the capabilities of classical computers. A quantum computer will be able to solve those problems, identifying unusual patterns for a range of applications.[14] By understanding the structure of such applications, imaginative managers will be better able to conceive of business opportunities that are well outside our current limitations.

Most important, you will need to consider the cost of quantum computing (on an instructions per second scale) relative to the *opportunity* cost of not having certain applications. Thinking in these terms will also help you to explore current alternative computing solutions, such as a graphics processing unit (GPU) cloud.

Inventory your in-house and outsourced computational and data capabilities

Take inventory of your data, software, and hardware capabilities, including those which use the cloud. The most expedient way to get started is to consider the data you already have available, whether or not it is being used, and identify a problem that might be solved or expedited by quantum computing. From a strategic perspective, quantum computing will mean accessing more hardware through the cloud, so evaluate what increased dependence on your cloud provider would look like.

Get Quantum-Ready Now

Rather than wait for innovators to make quantum computing widely accessible for business applications, managers can invest in quantum-inspired computing, which is already available, and gain a competitive advantage. When quantum computing does become widely available, these managers will be poised to take advantage of it. Companies like Toshiba, Hitachi, and Fujitsu have made quantum-inspired computers available on the cloud either directly from the manufacturer or, in some cases, through Amazon Braket. Quantum-inspired computation offers not only faster computing but also the ability to find several "good" solutions in a short time. Traditional binary computers, by contrast, sometimes burn through the available solution time, spinning their wheels in the search for a single near-optimal solution and end up settling for a single sub-optimal one.

In 2021, Quantbot Technologies LP, a multi-billion-dollar hedge fund manager, became quantum ready using Toshiba's SBM quantum-inspired computing on the cloud. In managing portfolios, the firm uses machine-learning algorithms to find possible alphas, the signals that indicate higher returns. However, these signals are noisy and may interact with each other. Quantbot's problem was how to best combine these signals to maximize the returns of a portfolio while containing risk to an acceptable level.

A team of Quantbot data scientists and a technologist adapted open-source code from Carnegie Mellon University (CMU) to tailor it to their problem before accessing Toshiba's SBM directly on the cloud. Within two minutes, we had twenty near-optimal solutions. In contrast, it had taken us several hours to find only a few sub-optimal solutions using a classical solver on a traditional digital computer. We then ran a retrospective simulation of 252 trading days of decision making which compared the effectiveness of the twenty near-optimal solutions produced by the quantum-inspired system with the existing binary-produced solutions, tracking risk, return, and Sharpe ratio. All twenty new solutions surpassed the previous solutions obtained with traditional means on every metric (see Figures 1 and 2). This dominance was not surprising; in the past, firms used heuristic algorithms on traditional computers because, even after hours of computation, finding an optimal solution would be too difficult. The surprising discovery was the excellent quality of the solutions that a quantum-inspired approach could find in just a couple of minutes.

The Choice for Executives

Computing speed continues to grow exponentially, with floating-point operations per second (FLOPS) doubling every 1.3 years, the number of transistors per chip doubling every two years (in keeping with Moore's Law), and chips becoming ever more integrated. At the same time, the use of refined algorithms in software continues to advance the abilities of commercially available solvers, such as Gurobi and CPLEX, which take advantage of new architectures and are increasingly available on the cloud.

Add to this mix the potential of quantum computing architectures, even in their current experimental form. Competition between these

FIGURE 1: All twenty quantum solutions provided higher returns (profit and loss, blue dots) and Sharpe ratios (red dots) than the binary solutions (normalized as red dashed line) then in use.

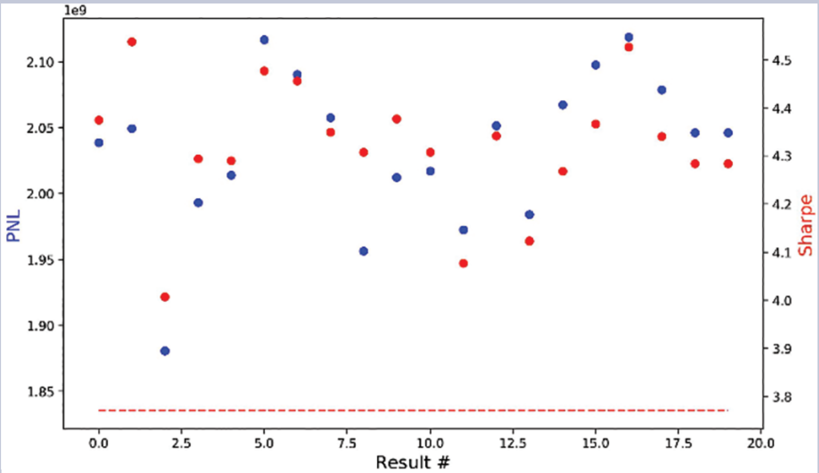
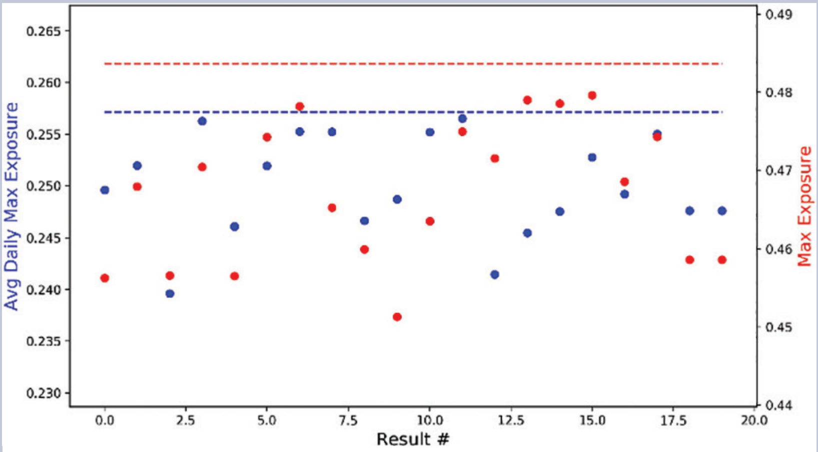


FIGURE 2: All twenty quantum solutions provided lower average (blue dots) and lower maximum daily (red dots) risk exposure than the binary solutions (dashed blue and red lines) then in use.



Quantum-inspired computing does have limitations which quantum computing does not.

architectures, and the resulting enhancements, can only benefit their eventual users.

Executives may wonder why they should pursue quantum readiness now. After all, Gartner coined the term "hype cycle" to describe the experience many firms and individuals have had with new technologies: unrealistic expectations at the outset, followed by a trough of disappointment and then slow learning (see Figure 3).[15] So why not wait and learn from the mistakes of others who have jumped early, tried, and failed?

Because if a company wants to have a competitive advantage, it must get quantum ready now. Information technology has become a utility: having it does not confer a competitive advantage, but not having it is a significant disadvantage.[16] But all that is far ahead; in the short term, you get competitive advantage by being ahead of your competitors and face a competitive disadvantage if you are behind them (Figure 4).

Quantum-inspired computing is already available on digital computers. It is the basis for the low-risk approach we suggest, offering companies the opportunity to become quantum-ready now. By doing so, you are likely to get better and faster solutions right away, and when quantum computing becomes widely accessible, you can use the same algorithms and applications and find your company well ahead of the competition.

Of course, managers may wonder why they should bother switching to true quantum computing if quantum-inspired computing is good enough, especially given the continually increasing speed of chips and thus digital computers. So it's important to understand that quantum-inspired computing does have limitations which quantum computing does not. At this time, quantum-inspired computing can tackle a limited set of complex problems, specifically those that can naturally be mapped to quadratic unconstrained binary optimization (QUBO). These problems do not require too many new variables or approximate continuous variables with discretization, such as binary classification in machine

FIGURE 3: The Gartner Hype Cycle, tracing inflated expectations. followed by disillusionment, and slow learning, eventually arriving at productivity (Source: Gartner).

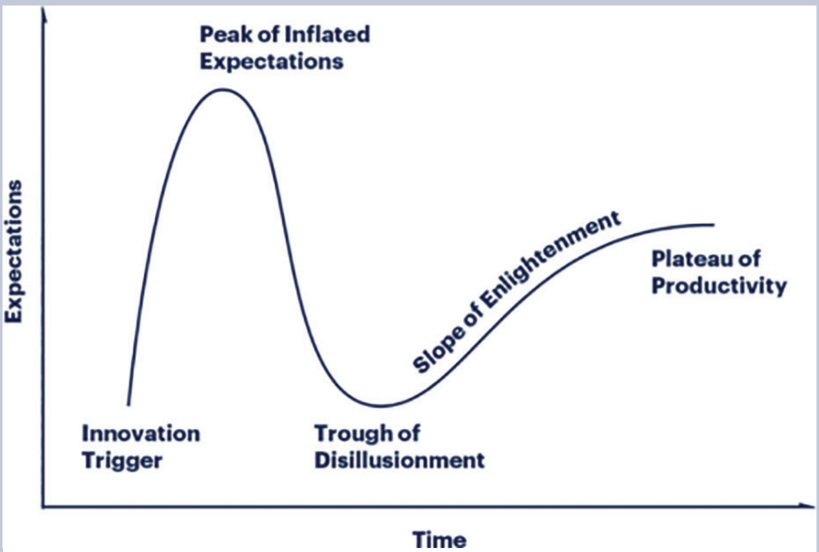
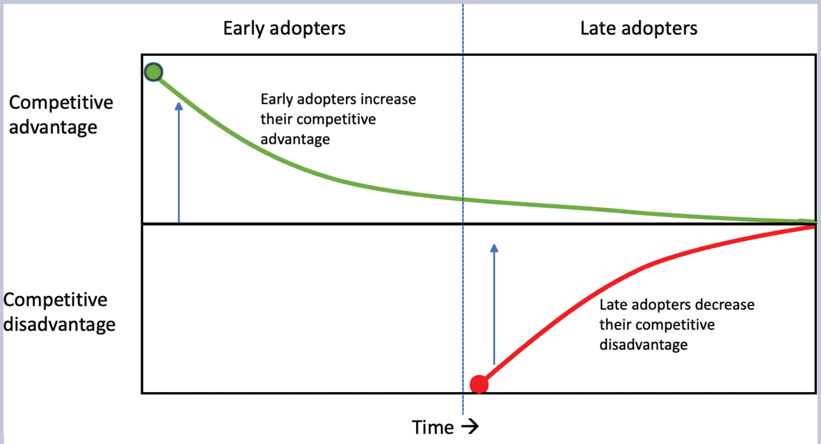


FIGURE 4: Some companies adopt technology early out of greed for a competitive advantage. Some wait until others have adopted it, when fear of being at a competitive disadvantage forces their hand.



learning. Such computing is not suitable in many situations, and is especially unsuitable for studying quantum chemistry and materials. Even when the data for, say, machine learning contains unusual patterns, quantum-inspired computing may not be helpful because such patterns exceed the abilities of digital computers, regardless of architecture. In such cases it makes good sense to wait for actual quantum computers.[17]

And digital computers are not going to be replaced by quantum ones. The fastest-growing costs and energy consumption stem from computing, whether it be server farms, the notorious bitcoin mining, or time-consuming financial calculations and simulations. While quantum computing does promise speed, its cost and energy consumption have not yet become clear and depend heavily on which architectures become practicable. So even when quantum computers become widely accessible, digital computers will likely shoulder most of the vast burden of computation for several decades.

> Quantum computing is only one of many readily confused quantum technologies.

And quantum computing is only one of many readily confused quantum technologies that include sensors and communications. Though quantum computers have recently been in the news as a possible threat to cryptography, this danger is merely theoretical. Managers need not worry about the security of their systems at the current stage of quantum computing development.

Instead, they can and should invest in quantum-inspired computing today and prepare for the extraordinary possibilities of true quantum computing tomorrow. ■

Author Bios

ManMohan S. Sodhi is a Professor of Operations and Supply Chain Management at Bayes Business School, City, University of London. He researches supply chain management, risk, and sustainability. He earned his Ph.D. from UCLA in non-deterministic computing and operations research. He has worked on large-scale mixed integer-and-linear programming problems. m.sodhi@city.ac.uk

Sridhar Tayur is the Ford Distinguished Research Chair and University Professor of Operations Management at Carnegie Mellon University's Tepper School of Business. He earned his Ph.D. in operations research and industrial engineering from Cornell University. He founded SmartOps (acquired by SAP in 2013), which is used for enterprise inventory optimization in over 700 global supply chains. In 2018, he founded the field of quantum integer programming (QuIP) to solve industrial-scale optimization problems. stayur@cmu.edu

Endnotes

1. ENIAC, or the Electronic Numerical Integrator and Computer, was the first programmable, general-purpose digital computer made in 1945 that remained in operation until 1956. It had a speed of about 1,000 times that of electro-mechanical machines and 2,400 times faster than a human. Towards the end of its operational use, the ENIAC contained 18,000 vacuum tubes, 7,200 crystal diodes, 1,500 relays, 70,000 resistors, 10,000 capacitors, and approximately 5,000,000 hand-soldered joints. It weighed 27 tons, occupied 1,800 sq feet, and consumed 150 kW of electricity.
2. Feynman, R.P. Simulating physics with computers. Int J Theor Phys 21, 467–488 (1982). https://doi.org/10.1007/BF02650179
3. Turing, A.M., 1936. On computable numbers, with an application to the Entscheidungsproblem. J. of Math, 58: 231-265.
4. Shannon, C.E., 1948. A mathematical theory of communication. The Bell System Technical Journal, 27(3): 379-423. Doi:10.1002/j.1538-7305.1948.tb01338.x
5. Ghose, S. 2020. Are you ready for the quantum computing revolution? HBR. Sep 17, 2020. Accessed https://hbr.org/2020/09/are-you-ready-for-the-quantum-computing-revolution?autocomplete=true
6. Ruane, J., McAfee, A., and Oliver, W.D., 2022. Quantum computing for business leaders. HBR. Jan-Feb issue.
7. Biondi, M. et al. 2021. Quantum computing use cases are getting real—what you need to know. McKinsey Digital. Accessed https://www.mckinsey.com/business-functions/mckinsey-digital/our-insights/quantum-computing-use-cases-are-getting-real-what-you-need-to-know?cid=other-eml-alt-mip-mck&hdpid=fabd4b4b-d2ed-4376-8bb8-37c3ac7b7607&hctky=1151117&hlkid=a7a83128cf484597b611c01720d2d79e.
8. Benioff, P. 1980. The computer as a physical system: A microscopic quantum mechanical Hamiltonian model of computers as represented by Turing machines. Journal of Statistical Physics, 22(5):563– 591.
9. Manin, Y.I. 1980. Vychislimoe i nevychislimoe (Computable and Noncomputable), Moscow.
10. Feynman, R.P. Simulating physics with computers. Int J Theor Phys 21, 467–488 (1982). https://doi.org/10.1007/BF02650179
11. Quantum algorithms may provide polynomial rather than exponential speedup, but this may be adequate for many practical-sized problems. See Aaronson, S. 2005. Guest column: NP-complete problems and physical reality. ACM SIGACT News 36(1):30–52. Accessed at https://doi.org/10.1145/1052796.1052804
12. Ruane, J., McAfee, A., and Oliver, W.D., 2022. Quantum computing for business leaders. HBR. Jan-Feb issue.
13. Bova, F., Goldfarb, A., and Melko, R. 2021. Commercial applications of quantum computing. EPJ Quantum Technol. 8, 2. https://doi.org/10.1140/epjqt/s40507-021-00091-1
14. Bernal, D.E., Ajagekar, A., Harwood, S.M., Stober, S.T., Trenev, D., You, F. 2022. *Perspectives of Quantum Computing for Chemical Engineering*. Accessed at https://doi.org/10.1002/aic.17651
15. Sodhi, M.S., Seyedghorban, Z., Hossein, T., and Simson, D. 2022. Why emerging supply chain technologies initially disappoint: Blockchain, IoT, and AI. *Production and Operations Management*. Accessed at https://doi.org/10.1111/poms.13694.
16. Carr, N. 2003. IT doesn't matter. *Harvard Business Review*. Accessed at https://hbr.org/2003/05/it-doesnt-matter.
17. Bernal, D.E., Ajagekar, A., Harwood, S.M., Stober, S.T., Trenev, D., You, F. 2022. *Perspectives of Quantum Computing for Chemical Engineering*. Accessed at https://doi.org/10.1002/aic.17651