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Applied Quantum Computing for Today's Military

ATARC Quantum Working Group
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Quantum computing technology supports numerous applications beneficial to the Federal Government. The purpose of this paper is to delve into uniform military application possibilities and provide some guidance that directly relates to the language within Section 214 of the National Defense Authorization Act of Fiscal Year 2021 (P.L. 116-283). This section updated the quantum information science and technology research and development program within the Department of Defense.[1]

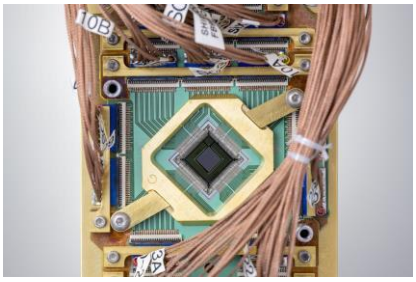
The aim of this paper is to help outline how military uniform services should think about utilizing today's commercially available quantum computing technologies to support their mission objectives in the near term. This paper will not highlight quantum technologies which are outside the scope of Section 214. It will focus on potential applications where quantum computing technology can help within the next 1-3 years.

Section 214 directed each military department to:

1. Develop and annually update a list of technical problems and research challenges which are likely to be addressable by quantum computers available for use within in the next one to three years, with a priority for technical problems and challenges where quantum computing systems have performance advantages over traditional computing systems, in order to enhance the capabilities of such quantum computers and support the addressing of relevant technical problems and research challenges.

2. Establish programs and enter into agreements with appropriate medium and small businesses with functional quantum computing capabilities to provide such private sector capabilities to government, industry, and academic researchers working on relevant technical problems and research activities.

WHAT IS QUANTUM COMPUTING?



Quantum computing is technology designed to harness the principles of quantum mechanics, a theory in physics which explains properties of nature on the atomic and subatomic levels. While classical computers encode information in bits that represent a value of 0 or 1, quantum computing uses quantum bits or qubits. Qubits have a unique ability to exist in more than one state at a given time. Superposition and entanglement are two features of quantum mechanics on which these powerful systems are based.

Quantum computing capability could allow a monumental speed up of problem solving up to 100 million times faster than traditional computers. The result is quantum computers can handle operations at speeds exponentially greater than conventional computers and consume much less energy. Simply put, quantum computers are beginning to demonstrate solving of some problems much faster than classical computers, and even tackling certain problems which are beyond the capabilities of today's classical computers.

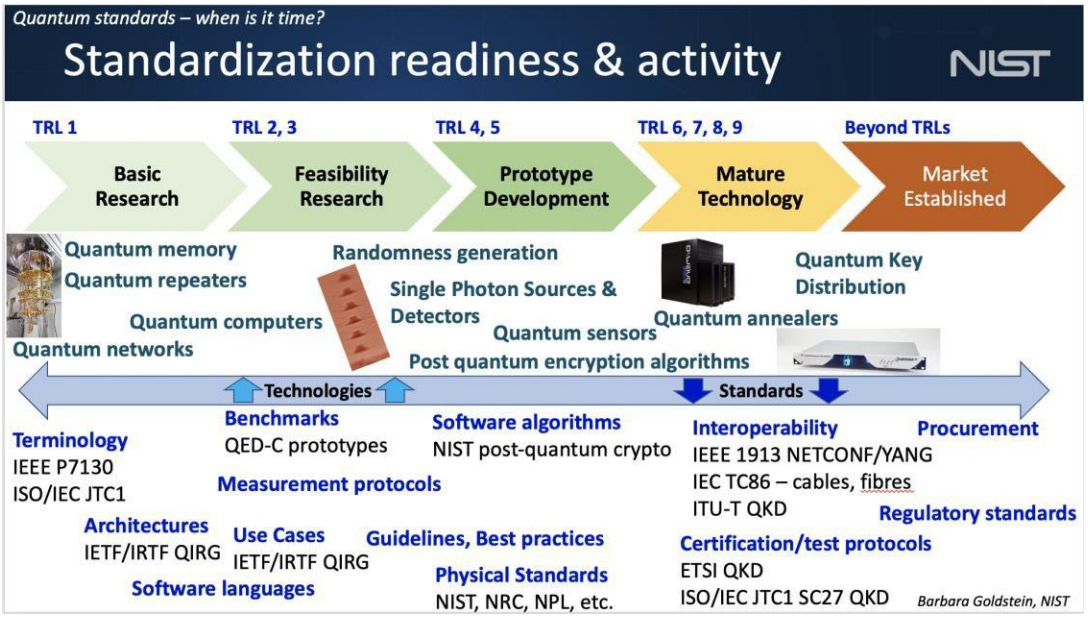
[1] https://www.govinfo.gov/content/pkg/BILLS-116hr6395enr/pdf/BILLS-116hr6395enr.pdf

There are numerous foundational approaches to quantum computing hardware such as gate model, annealers, topological and others. Under the gate model quantum computing, a quantum logic gate is a basic quantum circuit operating on a small number of qubits which become the building blocks of quantum circuits. With annealing quantum computing (which is a type of adiabatic quantum computation), the method is to select optimal solutions of problems from a very large number of possible solutions by taking advantage of properties specific to quantum mechanics like: quantum tunneling, entanglement and superposition. Annealing quantum computing harnesses the natural tendency of real-world physical systems to find low energy configurations. Topological quantum computing describes the structures that experience physical changes, such as: being bent, twisted, compacted, or stretched; yet, the qubit still maintains the properties of the original form.

Quantum computing chips can be superconducting fabrications, ion traps, silicon, photonics, etc. Qubits are fragile so noise, heat, and other factors impact their capabilities to complete a computation. However, private industry innovation has provided significant progress in the size and robustness of the qubits, providing some error correction methodologies, and therefore, the technology is now able to tackle many practical mission-scale applications.

The quantum computing hardware and software industry is expanding and maturing. Innovations in the private sector allow for several of today's real-world problems to be addressed by practical quantum applications. Additionally, NIST has been following the quantum ecosystem and its readiness.

The quantum computing hardware and software industry is expanding and maturing. NIST has been following the quantum ecosystem and its readiness. The Quantum Economic Development Consortium (QED-C), which was established by Congress, is a consortium whose mission is to enable and grow a robust quantum based industry and supply chain in the United States. Their members are commercial, academia, and federal research centers who are engaged in the quantum industry in the United States.



The push for access to quantum computing via cloud platforms has broken down the barriers to utilizing this powerful computate technology. Cloud access could allow all service branches to benefit from the power of quantum computing without having to invest in the purchase nor maintenance of quantum computing hardware. Moreover, the expansion of hybrid solvers, which takes the benefits of both quantum computing and classical

computing would allow governments to get the benefits of both computing technologies, providing a pathway to process mission-scale problems. This is what is called applied or practical quantum computing.

MILITARY PROBLEMS THAT COULD BE SOLVED WITH TODAY'S QUANTUM COMPUTERS

A recent study by faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, discussed possible quantum technology for a variety of military applications. According to the National Defense Strategy of 2018, rapidly innovating the Joint Forces is a focus, and applied quantum computing bridges the divide between theoretical and real-world by developing programs and applications to solve today's problems. Speaking before the Defense Innovation Board in 2018, Michael Hayduk, the current deputy director of the Air Force Research Lab Information Directorate, described quantum computing as a very disruptive technology,[2] but the department has not begun to fully implement practical quantum computing. As the Services begin to address the requirements set forth in Section 214, some potential areas are outlined below where quantum computing could assist the Services and meet the intent of the NDAA requirements. This list is not intended to be exhaustive of all applications.

- **Battlefield or Warfighter Simulations**: These exercises are an integral part of military training, and cloud computing has provided the infrastructure to migrate an entire simulation environment into a virtual environment. Cutting-edge simulation and mission rehearsal are of growing importance to the Services and COCOMs. At the 2019 Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), USSOCOM's Director of Training, Doctrine and Capability Development, MG Robert Karmazin, highlighted the application of emerging technologies, saying "SOCOM needs to expand the use of transformative technologies."[3] Quantum computers, along with virtual reality, augmented reality, mixed reality, and AI machine learning capabilities will all be critical for mission preparedness. The current trend is to perform many simulations for a mission to provide a more complete response and combine that with situational awareness intelligence. The goal is for a decision to be based upon both situational awareness and incorporated simulated possible situation evolution. Applied quantum computing, which can be enriched by quantum-enhanced AI, could be utilized by defense planners for mission-scale simulations of military deployments, and other scenarios, to provide real-time or near real time analysis to commanders.

- **Radio Frequency and Satellites:** The Department of Defense heavily relies on electromagnetic radiation characterization for intelligence, surveillance, Identify Friend or Foe (IFF), and reconnaissance (ISR) applications such as missile early warning and signals intelligence. Individual branches of the military are allotted significant ranges of frequency bands to enable various equipment and applications to support mission objectives.[4] Adversaries understand the department's use of spectrum, and have developed weapon systems, particularly electronic warfare (EW) platforms, which were specifically designed to interfere with or eliminate the Department's ability to effectively use or analyze the spectrum. Quantum computing applications could help with better understanding of adversary movements. In 2019, Ned Allen, Lockheed's chief scientist, says a magnetometer is great at detecting magnetic anomalies. One can compare anomalies detected against known maps. This not only allows navigators to determine where militaries are, but, because a magnetometer also indicates the orientation of magnetic fields, it has the capability to determine the direction of ships and submarines.[5] In an April

[2] https://spacenews.com/pentagon-sees-quantum-computing-as-key-weapon-for-war-in-space/
[3] https://www.militaryaerospace.com/computers/article/14183981/military-simulation-mission-rehearsal-computing-computer/
[4] https://fas.org/sgp/crs/natsec/R46564.pdf
[5] https://www.technologyreview.com/2019/01/03/137969/us-china-quantum-arms-race/

2020 academic paper, quantum computing was highlighted as a potential transformative technology to enhance operations in the space industry by reviewing geospatial data through accelerated optimization and machine learning processes. Quantum computing may be able to play a role by enhancing signal analysis, sensor fusion, imagery, analyzing geospatial data, and optimizing radio frequencies. All of these could provide faster and more efficient identifications of adversary military movements and better situational awareness and reconnaissance.

- **Logistics Management:** New tools to manage the mission-scale end-to-end military logistics enterprise will be critical and could facilitate faster and more effective decision-making, as well as dynamic planning in an increasingly complex environment. Quantum computing technologies can consider new ways to model and analyze diverse and dynamic processes that exist at globally distributed locations and provide efficient and effective logistics solutions. DHL, one of the world's leading logistics companies, reports that, "optimizing supply chain processes is considered to be the primary use case of quantum computing for the logistics industry, enabling real-time dynamism that could never be achieved by desktop PCs or supercomputers."[6] Volkswagen has also developed quantum computing algorithms which help with traffic flow optimization. Beyond route optimization, practical quantum computing could be a key technology in maximizing the simultaneous storage space of resources which are needed to be transported globally to provide mission assistance across the military fleet of ships, aircraft, planes, and trucks.

- **Supply Chain Optimization**: Military supply chain is an integrated and critical cross-functional approach to procuring, manufacturing and delivering goods and services. The enormous supply system has over hundreds of thousands of suppliers, across multiple times zones, and costs billions of dollars annually. In the private sector, many companies are looking at quantum computing to help update and modernize their supply chain management programs. BMW is beginning to work with quantum computing to help make better supply chain business decisions. Quantum computing could enable smarter supply chain decisions and enable end-to-end supply chain visibility and provide cost savings for the military.

- **Energy Management:** According to the 2019 CRS Report, Department of Defense Energy Management: Background and Issues for Congress, energy management is a critical focus of the military and is also another use case which could utilize practical quantum computing. UPS has been using On-Road Integrated Optimization and Navigation (ORION), its route optimization AI algorithm. This algorithm has reduced fuel consumption by over 10 million gallons, carbon emissions by 100,000 metric tons and avoidable costs by $300 million to $400 million annually.[7] This same type of energy optimization has been identified as a potential place for applied quantum computing to drive fiscal and financial efficiencies that align with the National Security Directive and lead to cost savings for the military.

> The U.S. Department of Defense consumes more energy than any other federal agency— 77% of the entire federal government's energy consumption. Energy management is integral to DOD operations. From running bases and training facilities to powering jets and ships, DOD relies on energy to maintain readiness and resiliency for mission operations. Energy efficiency— providing the same or an improved level of service with less energy—over time can reduce agency expenses, particularly at an agency like DOD, where energy represents roughly 2% of the department's annual budget.
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> *Source: Department of Defense Energy Management: Background and Issues for Congress, GAO Report, July 25, 2019*

[6] https://www.dhl.com/au-en/home/insights-and-innovation/thought-leadership/trend-reports/quantum-computing.html
[7] https://www.forbes.com/sites/forbestechcouncil/2021/02/05/how-quantum-computers-could-cut-millions-of-miles-from-supply-chains-and-transform-logistics/?sh=51ab07a625a9

- **Predictive Maintenance**: Military fleet maintenance is a continual problem for the Services. According to the Government Accounting Office (GAO), military services continue to rebuild readiness, but that work will take many years. In their report released in December 2020[8], GAO specifically highlighted the Navy and Marine Corps fleet readiness challenges, however, all branches of the military have fleet maintenance concerns. GE Research has built an early application aimed at predictive maintenance and logistics management to help with preventive maintenance and scheduling repairs for their equipment.

  Volkswagen has also built a prototype quantum application to help with driving efficiencies in scheduling their company paint shops. Such applications could be extremely useful for the military service branches given the difficult task of maintaining their large and global fleets which are deployed across many different environments. Quantum computing applications could be designed to drive efficiencies with predictive maintenance and optimize repairs.

- **Autonomous and Robotic Vehicles**: As the military fields unmanned and robotics platforms, it provides an increase of intractable problem sets that today's practical quantum computers could assist. There must be harmonization to ensure autonomous vehicles coordinate their movements to ensure optimal efficiency and achieve mission objectives. In the private sector, DENSO Corporation, a leading supplier of advanced automotive technology, developed a proof-of-concept aimed at optimizing control of automated guided vehicles on their factory floors. The Services could utilize quantum applications for optimizing autonomous vehicles as well as unmanned and robotic systems.

- **Medical Advancement & Response**: Currently, many private sector pharmaceutical companies are using quantum computing for drug discovery. Roche, one of the world's largest pharmaceutical companies, has stated that quantum computers offer greater computational power and have enormous potential for the industry, citing quantum enabled simulation of molecules to facilitate earlier and more accurate development of new medicines. In biomedical imagery, the technology can identify topological changes that are caused by a disease. Novartis, another multinational pharmaceutical company, has also stated that quantum is a key emerging technology that they are using for inventing new medicines and testing their efficacy. GlaxoSmithKline recently published a paper on bioRxiv looking at the role of hybrid quantum computing on peptide sequences in expressible mRNA, demonstrating benefits in protein folding. Military applications leveraging quantum computing could be used for complex simulations to design medical advancements that could be used in the field.

- **Material Sciences**: Scientists at the Argonne National Laboratory and the University of Chicago have been using quantum computers to simulate realistic molecules and complex materials.[9] Oak Ridge National Laboratory just announced research with the University of Tennessee, Knoxville and Purdue University where they harnessed the power of quantum annealing for material science. Paul Kairys, a student at UT Knoxville's Bredesen Center for Interdisciplinary Research and Graduate Education announced the development of new solutions to enable materials simulations on real-world quantum devices.[10] In the private sector, OTI Lumionics is using cloud based quantum computing and hybrid algorithms as the building blocks for the next-generation of OLED display technology. The military could benefit from advancements in display technologies and other material sciences powered by today's quantum computing technologies.

[8] https://www.gao.gov/assets/720/710981.pdf
[9] https://www.anl.gov/article/solving-materials-problems-with-a-quantum-computer
[10] https://www.ornl.gov/news/quantum-computing-enables-simulations-unravel-mysteries-magnetic-materials

- **Emergency Response**: The military is routinely called upon to respond to emergencies at home and abroad. Reducing response times during an emergency can be critically important, and quantum computing could assist with predictive resource placement and other important factors. For example, as the systems grow and become more powerful, quantum computing could analyze real-time and near-realtime atmospheric changes and incorporate those into predictive analytics for responses to hurricanes, wildfires, and floods including providing optimal staging locations in rapidly changing conditions. Masayuki Ohzeki, a co-founder of the Tokyo-based Sigma-i company has used quantum computing to develop optimum tsunami evacuation routes and was working on route planning for transporting large numbers of COVID-19 patients to and from a medical facility.[11] Quantum computers could also help with assessing viral spread, as highlighted by University of Alabama researcher Brian Britt such as assessing viral spread in networks including another coronavirus (COVID-19) style outbreak.[12] His research foundthat quantum computers could continuously monitor data to identify any potential flare -ups for rapid resources deployment. Whether it be a natural or manmade emergency, quantum computing applications can expedite analysis during a crisis where response time is critical.

- **Tracking Space Debris:** There are millions of pieces of space junk flying in low Earth orbit (LEO), most of which is comprised of human-generated objects. These small pieces of spacecraft, tiny flecks of paint, pieces of inoperable satellites, are building in size and scope, and the volume of debris in LEO poses a problem for the whole planet. NASA, the Air Force, and the newly formed space defense force will have to navigate through the space debris junk yard in LEO, and current classical computing capability are not sufficient for tracking and model movement of debris in orbit. In the UK, there has been a discussion about how quantum computing might be able help with space debris and space traffic management to create better tools for preventing potential collisions and managing the many satellites now orbiting Earth.[13] Quantum computing has been identified to help with satellite optimization, and there is a potential for creative thinking regarding the ability for quantum computing and hybrid solvers in modeling and tracking space debris.

- **Quantum-Safe Communication:** Quantum computing is a huge opportunity but also poses majorand systemic risks for cybersecurity. Quantum computers will be able to break the public-key standards that are used underlying the security of most IT protocols. Quantum computers are, yet, not powerful enough current cryptographic standards. On the other hand, the threat is already present since with the "*Harvest Now, Decrypt Later*" principle, data can already be collected, stored and decrypted in a few years once a powerful-enough quantum-computer will be available. The declassification time of many secrets can be longer than the expected delivery of a sufficiently large quantum computer. The quantum issue on cybersecurity is very actual. In 2016, NIST decided to start a standardization process whose goal is to develop new public-key quantum-resistant standards. This new generation of public-key standards will be defined by 2022. A complementary answer to the quantum threat is provided by quantum cryptography. A cryptography security based on the law of physics, particularly quantum-key distribution and quantum-random number generator. The deployment of these new technologies can significantly affect the cyber-security infrastructure (key size, file format, etc.) and there is a potential to carry tests on a restricted functional perimeter of the infrastructure providing education on the threat, gaining expertise and disseminating learnings relating to quantum-safecryptography.

[11] https://spectrum.ieee.org/tech-talk/computing/hardware/can-quantum-computing-help-us-respond-to-the-coronavirus
[12] https://onlinelibrary.wiley.com/doi/full/10.1002/que2.29
[13] https://nqit.ox.ac.uk/index.php/article/quantum-computing-space-sector.html

RECOMMENDATION

The use of quantum sandbox initiatives within the Department of Defense to build out applications for the problems identified by uniform service are recommended. Section 214 on FY21 NDAA requests the identification of problems, but the next step would be to create a program within the department where all service branches could bring their identified problems for review and prioritization that align with technological capabilities.

Through the use case discovery, proof of concept and application development in a rapid sandbox environment, the military can utilize the power of the current quantum computing technologies to begin to address critical mission objectives. Through a program of development, there can be continual application innovation. And, as new technological capabilities emerge, the military can quickly develop useful applications for deployment ensuring our warfighters have access to the best emerging quantum technologies.

CONCLUSION

This paper provides an outline of the types of problems that can be solved with today's quantum computing technology, to help meet the objectives of Section 214 in P.L. 116-283. It highlights some of the potential applications of practical quantum computing to address critical military needs today and, in the future.

While quantum computing systems continue to advance, there are numerous use cases which can be explored today to help address critical mission objectives of the military services. Identifying the best applications for quantum computing today will provide needed intelligence for the military as it drives for optimization and increased efficiencies.