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Written evidence submitted by Manchester Metropolitan University (QUT0003)

This submission is made by Dr Alan Crispin, Principal Lecturer at Manchester Metropolitan University. He has been researching quantum annealing and related advanced search algorithms (called meta-heuristics) since 2011 with six peer-reviewed papers in this domain. He was the academic lead in an Innovate UK-funded Knowledge Transfer Partnership with ServicePower Technologies Limited which has just launched the first commercial application of quantum annealing in the domain of field service scheduling.

Executive summary

- Quantum annealing is a search algorithm that can find an overall optimal solution to a problem by leveraging quantum fluctuations in the annealing process
- The currently available D-Wave quantum processor uses a hardware array of superconducting flux quantum bits (qubits) for quantum annealing [Johnson et. al. 2011], but research led by Dr Alan Crispin at Manchester Metropolitan University has implemented a quantum annealing simulator that runs on conventional computers. It does not suffer from the same limitation on the number of qubits as is currently available with D-Wave processors. Its algorithm also allows for more flexible problem formulation compared to the Chimera graph architecture used by the D-Wave quantum processor
- We have shown that our quantum annealing technique, when correctly tuned, can be applied to scheduling and routing problems to improve worker productivity and save on fuel costs, which has economic and environmental benefits. Our research also shows that this approach is particularly suited to solving large-scale optimisation problems
- Through a Knowledge Transfer Partnership (KTP) with the company ServicePower Technologies Limited, we applied our quantum annealing approach to optimise scheduling for mobile workforces (field service agents). Testing shows that our algorithm finds solutions that are equal to or better than those found through simulated annealing
- Our algorithm has been successfully patented by the company and is expected to be rolled out into a commercial product for schedule optimisation in due course
- Significantly, our quantum annealing simulator runs on high specification consumer hardware; it does not suffer from the same limitation on the number of qubits as currently available quantum annealing hardware. Industry, including SMEs, can therefore solve large-scale optimisation problems using a quantum annealing approach today rather than having to wait for R&D to develop and validate new – and likely expensive – hardware solutions
- The focus of the Industrial Strategy and the Government Office for Science (GoS) report 2016 is on the development of quantum hardware, characterised by large qubit arrays. We argue that this prioritisation neglects the importance of research to simulate tractable quantum mechanical effects (e.g. tunnelling) using consumer class (high performance) workstations or cloud deployments
- We submit this evidence to highlight the importance of support and funding for further research to study and simulate quantum effects using conventional machinery

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- We recommend the Government encourages more applied research in the field of quantum simulation as we have demonstrated it is “market ready”. We suggest that funding mechanisms such as the KTP scheme would help researchers apply their expertise to real work problems and provide a clear commercial route to integrating quantum software into products.

Progress made on the recommendations in the Government Office for Science’s 2016 report

Recommendation 1 “*There is a strong case for continuing the UK National Quantum Technologies Programme to maintain our world-leading position in a promising and now globally emerging area of technology. There should be matched private sector investment in any future phase, to increase the level of industry commitment to the programme, and to accelerate the process of commercialisation”*

1. Research at Manchester Metropolitan University in the area of quantum annealing began in 2010 when we showed that a quantum annealing technique could efficiently solve difficult graph colouring problems. We discovered solutions to several well-known benchmark k-colouring instances, some of which had been open for almost two decades. [Titiloye, O., Crispin, A., 2011]

2. Subsequent research has shown that our quantum annealing technique, when correctly tuned, can be applied to scheduling and routing problems to improve worker productivity and save on fuel costs, with economic and environmental benefits. [Crispin, A., Syrichas, A., 2014; Syrichas, A. 2016]

3. Significantly, our quantum annealing simulator runs on high specification consumer hardware; it does not suffer from the same limitation on the number of qubits as currently available quantum annealing hardware. [Titiloye, O., Crispin, A., 2012 and Syrichas, A., Crispin, A., 2017].

4. Through a Knowledge Transfer Partnership (KTP) with the company ServicePower Technologies Limited, we applied our quantum annealing approach to optimise scheduling for mobile workforces (field service agents). Over two years we successfully created a quantum annealing algorithm to optimise large field service scheduling problems.

5. A patent for this algorithm was granted to ServicePower in December 2017 [Syrichas, A., Crispin, A., 2017, United States Patent 9,841,990]. ServicePower is rolling out the algorithm to customers as an optimisation option in the company’s latest release of its Optimization on Demand product [ServicePower 2017].

6. The successful KTP provides strong evidence that some quantum technology is already fit for commercialisation.

7. We suggest that a shared funding model is appropriate, because it significantly reduces the R&D risks and costs for companies, whilst promoting market-led uptake and investment of academic innovation.

8. We advocate a significant allocation of future funding to support partnerships to adapt and apply simulated quantum techniques. We have found the partnership model provides a

healthy balance between academic rigour and commercial pressures so projects progress with focus and efficiency.

9. The research community typically emphasises hardware development because the work requires large research budgets. There is a risk that the collective voice of this community may over-power the fact that quantum software has already demonstrated its capability and will be available on the market most likely within 12 months.

10. We also recommend a robust strategy to ensure that quantum technology does not become the preserve of Governments and national security services, but is developed in partnership with, and made available to, any company that would benefit from big data analysis or large scale optimisation capabilities

Recommendation 5: Regulation should not present a barrier to the use, deployment and commercialisation of quantum technologies. The National Programme should ensure regulators and standards bodies are aware of the capabilities of the technologies under development, so that regulations are formulated to realise the full potential of these technologies. Test-beds and road-mapping should be considered as a route to development of the regulations by government.

11. We believe that patenting of IP helps to stimulate competition and growth by facilitating economic valuation of innovation. The patenting of our algorithm was a key element of ServicePower's business strategy; the patent portfolio helps the company maintain a competitive market position and a strong company valuation. The patent also supports the company's reputation as an innovator and as an R&D-led organisation working with leading academics in the field. Patents also help companies evaluate the return from their R&D investments [Breitenstein, J., 2015].

12. We recommend development of research road-maps and test-beds – especially for quantum simulation – in close partnership with all stakeholders to ensure research is driven by market demand and geared at solving large-scale industry problems. Our research and testing shows that quantum annealing is particularly suited to large scale problems that are often beyond the scope for standard heuristics [Manchester Metropolitan University 2017]

Recommendation 6: The National Quantum Technologies Programme should work with the Alan Turing Institute, the Heilbronn Institute for Mathematical Research and wider academia to identify a set of example challenges which, if solved by a quantum computer or quantum simulator, would have important benefits to government, business and citizens. These challenges would involve algorithm research related to areas such as machine learning, artificial intelligence and the investigation of pharmaceutical drugs and new materials. Government could act as a demonstration client for some of these challenges.

13. From our industry interactions, we suggest that primary challenges in the public domain that are ripe for quantum optimisation would include: assignment and routing of first responders in emergencies; and rostering and task allocation, especially in large organisations such as the NHS, armed services or multinational corporations.

14. We looked at the vehicle routing problem using scientific benchmarks and found new optimal results in terms of improved objective costs (i.e. shorter route distances and reduced number of vehicles) satisfying capacity constraints [Syrichas, A., Crispin, A., 2017] .

15. Using real-world datasets, ServicePower ran comparative experiments using a standard optimizer (simulated annealing) and the quantum annealing optimizer. Quantum annealing universally outperformed the standard optimizer in terms of number of jobs successfully assigned and number of resources saved (trucks, people etc.) with the exception of an occasional draw. A typical quantum simulation assigned 5% more jobs for the same running time (23 seconds). This saving would scale significantly with larger datasets. [Syrichas, A., 2016]

16. Results from vehicle routing benchmark testing [Syrichas, A., Crispin, A., 2017] show that quantum annealing gives a percentage saving over previous best known values of 0.69%. Scaled up to a fleet of 70000 trucks (approximate size of Fedex's fleet, worldwide), we estimate a potential saving of nearly 9 million litres of fuel per day (based on an average 260 km per day, fuel consumption of 14.16 km/litre and three shifts per day for 336 days per year)

17. This type of optimisation has applications in many areas of business other than logistics such as reductions in administration overheads, higher service engineer productivity and improved cash flow. These improvements can all help to enhance customer satisfaction and retention [Manchester Metropolitan University press release, 2018]

Recommendation 10: The UK, through a competitive process overseen by the National Quantum Technologies Programme, should establish innovation centres. These centres would go beyond the scope of the current Quantum Technology Hubs, involving the co-location of academic and industrial partners with the requirement for matched funding from industry.

18. ServicePower's first-to-market release of quantum-enabled optimisation demonstrates how some quantum simulation is at the stage of commercialisation and applicable for solving/optimising large scale industry problems, including resource allocation. There is an increasingly strong driver for all organisations to optimise their operations to maintain a strong competitive position and reduce costs in the global market.

19. Co-localisation fits with the EU Smart Specialisation model. With a strong digital industry base, Manchester is well placed for such a centre, able to enhance quantum hardware research with expertise in quantum simulation techniques, such as our annealing and other meta-heuristics.

20. Manchester Metropolitan University's excellent track record in delivering successful KTPs, especially among SMEs in the area, is a particular strength. We currently have 21 live KTPs that expect to deliver significant growth in pre-tax profits within 3 years of completion mainly through new products and increased sales [Manchester Metropolitan University, 2018].

Recommendation 11: The programme partners in the UK National Quantum Technologies Programme, together with the Quantum Technology Hubs, should establish a body with the funding and sole remit to coordinate activities across the programme more effectively.

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21. We suggest the NQTB partners are too narrow and this situation perpetuates the drive in research and innovation towards the “classic” area of quantum research. Whilst we understand the strong pressures to develop quantum solutions for national security and infrastructure protection, we would welcome a broadening of scope to wider industry representation, including SMEs and representatives from outside of the “classic” quantum fields of research and application.

22. We would like to see greater recognition of the benefits and return on investment from smaller-scale investment and programmes to enhance quantum simulation research and applications. We maintain that benefits of quantum research should be affordable and accessible to all.

23. We welcome the establishment of the Quantum KTN as this will help to provide more of an industry focus, with greater awareness and dialogue around market needs and current problems.

24. We propose the KTN conducts a comprehensive study to identify the large-scale problems facing industry that are currently too complex to solve using conventional means. We recommend that this study especially considers problems that are too urgent to await commercial development of affordable quantum hardware, but lend themselves to quantum simulation [Electronic Times, 2017].

The current state of the UK quantum industry and its potential going forward, including particular strengths and challenges;

25. NQIT produced its report “The Commercial Prospects for Quantum Computing” in December 2016. It states: “Despite its infancy, confidence in the future of quantum computing is growing. Market Research Media have projected the quantum computing market to exceed USD 5 billion by 2020.” The report quotes ServicePower’s Chief Executive, Marne Martin (2013-18), saying “Quantum annealing is expected to take our scheduling products to the next level, providing the highest in cost reduction to our clients and improving their abilities to provide exceptional services to their own customers.”

26. Our testing of the quantum annealing has demonstrated its ability to improve outcomes (compared to simulated annealing) within similar timescales. The best performance uplift is observed in large-scale problems (see simulation data above). Moreover, quantum simulation can run on relatively inexpensive high end personal computers, making quantum simulation affordable and accessible to all users, including SMEs. Simon Cooper, Chief Technology Officer of ServicePower, said: “Quantum annealing, our latest innovation, has far reaching implications, not just in field service but in many different areas of life and business, especially when partnered with our state of the art field service management technology”.

27. One of the key challenges we have identified is the current speed of quantum annealing which typically runs 10 times slower than simulated annealing. While this is not a real issue for many problems (for example scheduling field service agents for the following day), the lack of a near-real time response may hinder its utility. However, in recent research we have developed the algorithm to run in parallel and successfully brought down the

processing time to near-match that of existing optimisation engines, with enhanced outcomes [Syrichas, A., 2016]

28. There is recognition in ServicePower globally of the benefit of KTP programmes, the return on investment from its KTP contribution, the value of the patent and its potential to underpin future company strategy, growth and competitive positioning

What research priorities there should be for quantum technologies and their possible uses, and who is best placed to undertake/fund that work;

29. The research at Manchester Metropolitan is unique and pioneering in its industry application of quantum techniques. Beyond D-Wave computers it is the only application of quantum annealing that is commercial, available and patented. We are unaware of similar teams engaged in similar research for practical goals with patent outputs.

30. As stated, our KTP has gone far beyond proof-of-concept; we have demonstrated a real uplift in optimisation performance on real-world data and the algorithm is expected to be made available to customers within 12 months.

31. We emphasise the scope for significant industry benefit in the application of quantum-based optimisation to deliver marked cost savings and greater productivity.

32. However, we also stress that further research (especially carried out by focused partnerships between academia and industry) into quantum annealing and other quantum simulation techniques is vital and should not be neglected due to the greater demands for funding from the hardware research community.

Any potential societal implications – positive and negative – of the development of quantum technologies, including on health, security, privacy or equality.

33. Quantum technologies promise significant socioeconomic impacts and are hailed as a key ingredient for our sustained growth and security (see above). We would also expect to see large-scale scheduling of self-driving cars, doctor rostering, rapid deployment environments, big data (e.g. medical biclustering, portfolio optimization) etc.

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Recommendations

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