HOW CAN QUANTUM COMPUTING BE APPLIED TO OPERATIONAL HEALTHCARE?

POTENTIAL USE CASES, IMPACT, AND IMPLICATIONS

Applied Quantum Computing (AQC) and The PSC have been working together to investigate how quantum computing techniques can be applied to a variety of commonly encountered and important operational challenges in healthcare. This paper seeks to set out some of the possible use cases and potential impact and implications of applying quantum computing.

What is quantum computing and why is it useful?

Quantum computing is a new approach to computation that makes use of quantum physics-based techniques. Quantum computers can be helpful in solving particular types of problems, one of which is **combinatorial optimisation problems**. In many cases, these problems can only be solved definitively by exhaustive testing all possible solutions before you can be certain the optimal solution has been found. In other cases, heuristic methods for large problem examples are used but these suffer from drawbacks, such as there is no guarantee of finding the optimal solution and the so-called algorithms may take a long time to find a result. Indeed, as complexity increases, combinatorial problems can take classical computers years to solve – quantum computing, in contrast, provides an opportunity to solve large problem instances much more quickly.

Quantum computation is an emerging technology and quantum computers are still being developed. It is likely to take 5-15 years before they can be deployed and their benefits can be fully realised.

How can it be applied to operational healthcare?

Healthcare provision in the UK accounts for approximately 11% of UK GDP[1] and is the single largest area of UK Government expenditure. In providing an efficient and comprehensive healthcare system, the NHS brings together many complex procedural tasks at a large scale on an everyday basis. Nevertheless, it is well known that the NHS faces many challenges in providing the scale and quality of care expected by patients, and it is widely expected that these challenges will continue. Consequently, there is a critical need to maximise efficiency and optimise the use of current and future resources.

There are potential opportunities for improvements in many aspects of healthcare service provision. Intrinsically many of the operational processes involved in delivering these services involve a form of optimisation to ensure available service capacity and patient benefit are jointly maximised. It is widely considered that quantum computational techniques could unlock solutions to complex optimisation problems of this nature.

Here we showcase two of the most promising use cases, where proof of concept has been shown by AQC, followed by a long list of other potential uses cases where the application of quantum computers could be beneficial.

[1] ONS *Healthcare expenditure, UK Health Accounts provisional estimates: 2022*

Proof of concept use cases

A Theatre planning – patient allocation	
In a nutshell	Allocating patients to the patient list for each scheduled theatre session to maximise utilisation
Description	Maximising the utilisation of a set of theatre sessions for a given speciality by maximising operating time through the optimal allocation of patients to sessions while avoiding waiting time breaches*.
Variables & constraints	• Patients require different procedures with varying complexity and consequently varying operating times • Patients have different priority ratings with different corresponding waiting times: P1 (most urgent), P2, P3, P4 (least urgent) • Surgeons have different operating capabilities (i.e., a portfolio of procedures they can perform) and typical operating times • Different procedures require different types of anaesthetists • Different procedures require different equipment • Sessions are normally 4 hours duration with very limited scope for overrunning • It may be beneficial for procedures to be performed by the consultant who conducted the patient's outpatient appointment - however this is not a requirement
Complications	• Patients must be provided with enough notice of their procedure • Complications in theatre may impact the length of the procedure • There may be last-minute cancellations (e.g., patient tests positive for covid-19)
Impact	• Current theatre utilisation is sub-optimal, typically at 75%, whereas the national target and best-practice is 85%[2], leaving scope for significant improvement • Theatres are a high-cost resource, therefore optimising utilisation has large financial benefits • Improved utilisation also reduces waiting times with a subsequent impact on patient outcomes

* Not all requirements may be able to be met simultaneously

B Urgent care planning	
In a nutshell	Allocating patients requiring urgent (but not emergency) care to a given set of care facilities to minimise waiting time
Description	Allocating patients presenting with a variety of conditions requiring urgent care to condition-appropriate care facilities (e.g., Minor Injuries Unit, Urgent Treatment Centre, Same Day Urgent Care, pharmacy) to minimise the overall waiting time (by considering the capacity of facilities) while seeking to ensure patients are seen within the target condition-dependent waiting times*. It is assumed that patients can be batched into cohorts and are periodically (e.g., every 30 minutes) assigned to treatment locations.
Variables & constraints	• Patients present with different conditions requiring different care with different target waiting times • There are several different care facilities/locations with different capacities and care capabilities • There are several possible times slots (windows) to which patients can be assigned • Travel time for the patient
Complications	• Requires information about the patient's condition in advance; however, this could be provided through NHS 111 which provides a 'triage' point and the ability to direct the patient

[2] Getting It Right First Time *Theatre Productivity*: https://gettingitrightfirsttime.co.uk/hvlc/theatre-productivity/

	• Requires available data on the capacity of different urgent care facilities • Requires operational and clinical model change across the system
Impact	• Large demand for urgent care services which often gets focused at A&E departments • Ability to even out demand by controlling flow of patients throughout the day, reducing patient waiting times and staff burnout • Solution is also applicable to allocating patients to GP and other primary care appointments

* In practice, the importance of meeting condition-dependent waiting times relative to minimising overall waiting time would be clinically determined and the model would be adjusted to reflect that clinical perspective

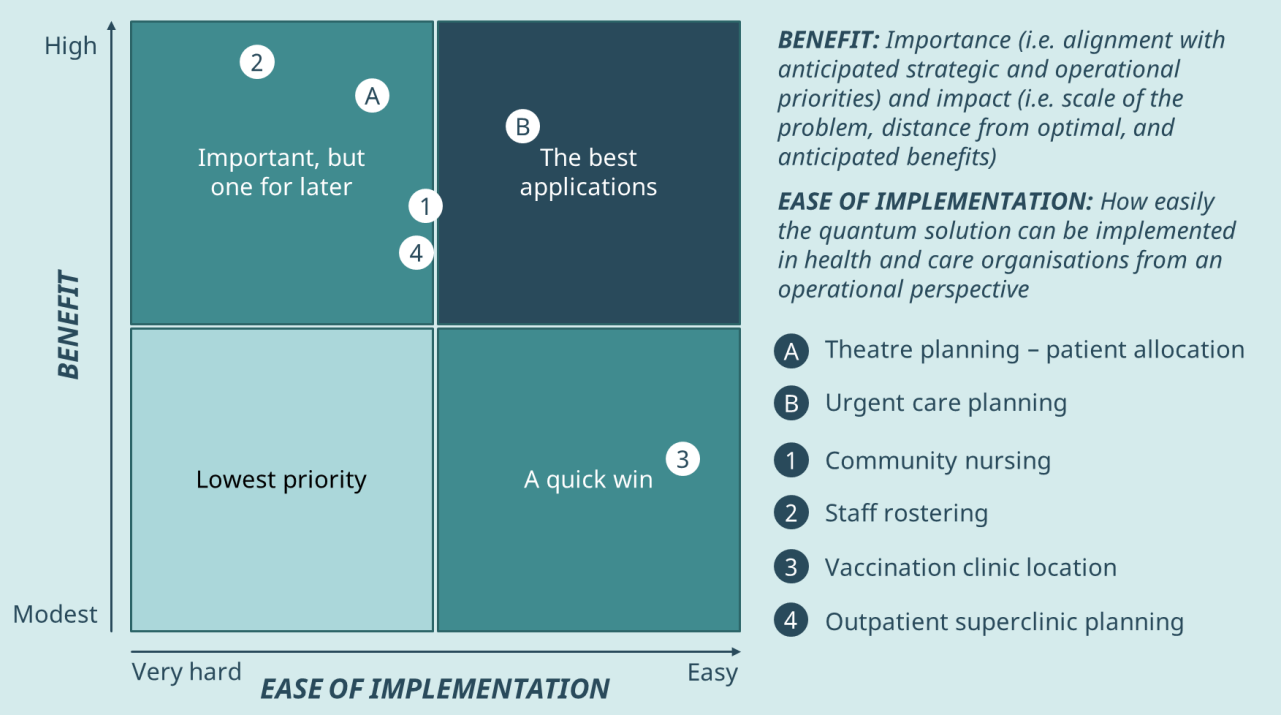
Long list of other potential use cases

1 Community nursing	
In a nutshell	Allocating staff to patients so that travel time (lost time) is minimised
Description	Identifying the optimal route for community nurses to take as they deliver care in people's homes (i.e., allocating them to patients) so that travel time is minimised, whilst also considering different modes of travel and traffic, and which staff will best meet the needs of the patient, including achieving continuity of care.
Impact	• Ability to see higher numbers of patients, reducing waiting lists • Reduction in staff costs per visit and travel costs • Large future benefit as more care moves 'out of hospital' and into the community • This application can also be extended to social worker and domiciliary care
2 Staff rostering	
In a nutshell	Allocating staff to rotas so that rotas are full (or have the fewest gaps) and staff availability constraints are met
Description	Staff must be allocated to rotas so that demand is met whilst considering which clinics/procedures/other activity needs to take place, required skill mix, and other constraints (e.g., staff leave and working hours).
Impact	• Staffing is currently a big capacity constraint and staffing costs are large, therefore optimising has large benefits • Whilst classical systems exist, they are separate for different disciplines, and rostering is often still done by hand • Scale of the use case varies depending on the number of different staff and departments/organisations, with complexity varying correspondingly • A similar use case involves allocating locum resources to rota gaps to minimise remaining vacancies, taking account of costs, suitability, and other constraints
3 Vaccination clinic location	
In a nutshell	Identifying where to locate vaccination clinics within geographical regions to maximise take up
Description	This use case identifies where vaccination centres within geographical regions should be located to maximise take up by considering travel times (to be minimised), clinic capacity, population size and demographics, and the proportion of the population already vaccinated.
Impact	• Higher vaccination uptake can reduce infection rates, improving patient lives and reducing pressure on the health system • One-off planning decision, however, could impact large populations • Applicable to seasonal clinics (e.g., flu) and future mass vaccinations (e.g., pandemic response, though covid-19 vaccination urgency has dropped considerably since 2020/21)

4	Outpatient superclinic planning
In a nutshell	Allocating patients to different clinic resources to maximise staff utilisation and minimise patient waits
Description	'Super-clinics' use multidisciplinary teams to run one-stop clinics with assessments, diagnostics, and procedures. Patients will follow different pathways through the clinic spending different times at each step. Staff/resources are also not fully utilised as they wait for patients. The optimisation problem is therefore how to assign patients to clinic resources to maximise staff utilisation and minimise patient waits, given a known cohort of patients will attend the clinic (i.e., not walk-in).
Impact	• The ability to plan more effectively will result in a big increase in efficiency, increasing the number of patients seen and reducing the number of staff required • Improved patient experience with shorter waiting times while at the clinic

Prioritisation methodology

We considered the relative priority of the different use cases to arrive at two use cases for proof of concept testing. This involved looking at the importance and potential impact of the use cases to operational healthcare, alongside how easy they would be to implement. This is captured in the below matrix.



Consideration was also given to the quantum suitability of the use cases, ensuring that the problems were appropriately complex for quantum computing to be applicable with meaningful results, whilst also having the ability to be simplified so that a proof of concept can be demonstrated.

What are the implications for operational healthcare?

Quantum computers are expected to be able to deliver "quantum advantage" sometime in the next 5-15 years and offer many potential benefits to operational healthcare challenges as outlined in the use cases above.

There are some considerations that should be made in terms of future adoption and implementation of quantum computers in operational healthcare settings, including:

- **Availability of data** – many of the use cases above require data on patients, resources, and other data as inputs to the problem
- **Culture/appetite for change** – some use cases require changes to current models of care and working practices
- **How systems, organisations, and staff can work together to maximise the benefits** – larger scale problems involving multiple systems, organisations, and staff will benefit most from quantum computing

The exciting work carried out by AQC and The PSC has provided an early demonstration of the applicability of quantum techniques to operational healthcare use cases, and has shown the potential significant and far-reaching benefits that quantum computing could offer many areas of the healthcare sector. There are plans for a continuation of the work in the form of an in-depth feasibility study that applies quantum techniques to a larger number of operational healthcare use cases on the path to developing an application with great societal value.

Acknowledgements

Applied Quantum Computing and The PSC would like to acknowledge the assistance provided by Hampshire Hospitals NHS Foundation Trust, without which this research project would not have been possible. We would also like to acknowledge our project partners, the National Quantum Computing Centre for their contributions in shaping the project in an advisory capacity. This work was undertaken with the support of a grant from the Science and Technology Facilities Council / National Quantum Computing Centre as part of its programme to develop quantum computing and its applications in the U.K. Applied Quantum Computing would additionally like to thank IBM who, through the IBM Quantum Partner programme, have provided access to certain quantum computer processors.

August 2023