# A Full-Quantum Solution to the BMW Vehicle Sensor Optimization Challenge Problem

Quantum Computing Inc.

July 2022

## 1 Executive Summary

The BMW sensor challenge seeks to use quantum technologies to find an optimal configuration of vehicle sensors for autonomous driving, with optimality defined by maximal coverage of the vehicle's surroundings at minimal economic cost.

Historically, commercially-available QPU architectures have only been able to process problems with very limited variable sizes, due to the number of qubits available to represent problem variables and the lack of connectivity to account for constraints. This limitation is due in large part to the extreme system requirements needed to create large scale quantum computing systems.

In 2021, Quantum Computing Inc. (QCI), took on the BMW sensor optimization challenge and generated a solution, leveraging a variational approach, Variational Analog Quantum Oracle ("VAQO") that enables QPUs to contribute to solving problems larger than the number of qubits available, as applied to a D-Wave quantum annealer. That demonstration provided a good example of how QCI software can be used to extend the capabilities of current quantum computing hardware. This software, QAmplify, includes VAQO and can be used to extend the qubit capacity of both gate-model systems and quantum annealers.

With the recent acquisition of QPhoton, a quantum photonics systems company, QCI has established a toolbox of new quantum hardware technologies, including Entropy Quantum Computing (EQC) that can be applied to the BMW optimization problem. This year, we present a 2022 solution based on EQC to directly solve a problem with 3,854 variables. Using an initial EQC prototype, a superior, feasible solution was obtained in six minutes of total runtime.

## 2 Approach – Entropy Quantum Computing

EQC operates on the most fundamental principles of quantum physics, especially its measurement postulate where the wavefunction of a quantum system will collapse to a certain eigenstate due to its interaction with a measurement apparatus–or broadly speaking, the surrounding environment. It is an orthogonal approach to existing architectures described above, which operate on closed quantum systems under extreme requirements to calm the effects of the environment and minimize their interaction with the environment.

By contrast, EQC operates on quantum open systems. It carefully couples a quantum system to an engineered environment, so that its quantum state is collapsed to represent a problem's desirable solution. As such, it operates reliably at room temperature and can support computations over a many-variable space, to provide powerful quantum solutions to real-world problems today.

The 2022 sensor challenge problem taken on with the EQC consists of $n = 3,854$ variables and 501 constraints. The problem (including constraints) was submitted directly to an EQC prototype in the form of an $n$–by–$(n+1)$ Hamiltonian matrix. Through the controlled interaction with the engineered environment, the system relaxed to a ground state, where the objective function and all of the optimality conditions were captured and subsequently analyzed.

## 3 Results

The EQC result provided a sensor configuration consisting of 15 sensors yielding 96% coverage of the criticality space. This practical solution demonstrates a clear advantage when compared with best alternatives. First, using QCI's classical solver CSample, the problem resulted in a significantly lower 62.8% coverage area for the same number of sensors (15). Second, using the VAQO approach demonstrated in our 2021 solution, we generated a result with a higher 99.8% sensor coverage, but at significantly higher costs using 373 sensors. Table 1 summarizes these data.

| Performance Parameter | EQC | VAQO | CSample |
|---|---|---|---|
| Coverage | 96% | 99.6% | 62.8% |
| Number of sensors | 15 | 373 | 15 |
| Runtime (sec) | 363 | 26373 | 197 |

Table 1: *Comparison of best results obtained by each solver. The Hamiltonian used was properly designed to take into account the physical constraints of the EQC system. Metrics meeting the practical feasibility bar are marked in green, and those failing to meet are marked in red.*

We also compared the EQC problem runtime to the runtimes for each of the alternative methods (Table 1). The EQC ran in a timeframe roughly comparable to the classical solver, and over 70X faster than the VAQO implementation. As seen, only EQC gives the optimal solution that meets the coverage, cost, and runtime requirements.

Furthermore, the EQC provided a stability that allowed us to run the problem repeatedly and iteratively. This ability to iterate through multiple development cycles demonstrates the usefulness of the EQC for business applications.

## 4 Discussion

Using an early EQC prototype, QCI has successfully run a 3,854 variable BMW sensor problem using an entropy quantum computer. To the Company's knowledge, there has not been a commercial quantum computing technology capable of processing problems of this scale and complexity. The results returned by the EQC represent the first known feasible quantum solution to this problem and compare favorably with both a classical solution (QCI CSample) running on a computer cluster and the previously run (2021) QCI variational algorithm (VAQO) in concert with a D-Wave system. This Entropy Quantum Computing demonstration represents a significant step toward building practical quantum systems for addressing business-relevant problems today.