

Classical and Quantum Optimization for Driving-Behavior Clustering: A Comparative Benchmark

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Abstract: This work presents a structured benchmarking study of classical and quantum optimization methods for the binary clustering of driving-behavior data. We compare Gurobi, Simulated Annealing, D-Wave quantum annealing, and Quantum Approximate Optimization Algorithm (QAOA).

We formulate driving-behavior analysis as a clustering problem over multivariate features extracted from simulated driving sessions under controlled stimuli. The experimental design considers “happy-to-angry” and “angry-to-happy” induced emotional transitions, which define the two reference groups used to evaluate the clustering outcomes. A broader methodological analysis of the driving simulation experiment is presented in [2]. The resulting optimization problem is formulated as a QUBO model, in which binary variables assign each driver to one of the two clusters to minimize the sum of intra-cluster distances derived from observed driving features.

A previous contribution [1] outlined the general framework and reported initial comparative evidence on classical and quantum methods, obtained under limited access to quantum hardware and validated on a restricted set of instances. The present work extends the results in [1] by providing a comprehensive and robust benchmarking analysis that incorporates a real-data validation, an in-depth assessment of Quantum Annealing (QA) on D-Wave and gate-based quantum optimization through the Quantum Approximate Optimization Algorithm (QAOA). The latter is simulated using CUDA-Q on both CPU and GPU backends. The study’s significance is further enhanced by additional real and synthetic instances.

In mobility-related applications, fast decision-making over high-dimensional and temporally structured data is essential. We assess solver performance in a near-real-time setting, measuring the extent to which quantum approaches can contribute to delivering reliable clustering solutions under strict time constraints. In this context, a solver can be considered effective as long as it returns a solution whose quality remains above an acceptable threshold in a reduced execution time. The probabilistic nature of the considered quantum methods (QA and QAOA) also suggests that post-processing strategies could further support the identification of higher-quality solutions in real-world applications.

The comparison is organized around four methods: Gurobi as an exact optimization baseline, Simulated Annealing as a classical metaheuristic, QA on D-Wave as the quantum hardware component, and QAOA simulated with CUDA-Q on CPU and GPU backends. All methods are assessed through a shared evaluation protocol considering solution quality, feasibility rate, clustering accuracy against the Gurobi reference and the ground-truth labels. Computational effort is evaluated through detailed timing analysis.

The quantum annealing solver exhibits stable execution behavior, with annealing times substantially independent of instance size within the tested range. The gate-based approach, classically simulated with CUDA-Q, shows improved performance on GPU compared to CPU. Given the current stage of technological development, traditional methods like optimization solvers and metaheuristics still represent the most reliable and cost-effective option for the considered problem, particularly on larger instances. As scalability and availability of quantum technologies increase, these findings provide practical insight into the conditions under which quantum optimization can effectively support driving-behavior clustering.

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References

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