Design and Application of Classical and Quantum Algorithms to Real-World Routing Logistics Optimizations

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Abstract– Optimization problems compels researchers to find the best possible solutions with regards to consistent and appropriate standard or customized metrics. A contemporary related trend enhances the traditional exact and heuristics approaches commonly utilized for NP-hard problems using Machine Learning techniques and the ever more important hybrid classical-quantum algorithms. Recently, an international competition called LMRRC requested its participants for innovative and effective proposals to a cargo routing optimization problem whose objective was to find a particular non-repeatable sequence of stops. This project shows an original methodology to successfully solve this problem, which is an improvement on the one we presented at LMRRC where we qualified as a top-performing team. This expanded methodology first focuses on this complex stops sequencing exercise and then seeks to generalize to cases where traditional GPS records of the delivery vehicle are received. Thus, it adds the determination and structuring of possible stops of the route, and then defines as well as dynamically analyses groups of stops using adaptable superpositions of multiple cost functions.

Keywords—Optimization Engineering, Cargo Routing, Transport Logistics, Classical-Quantum Computing, International Competition.

I. Background and Motivation

The leading companies in the field of logistics and distribution find themselves with the growing need to optimize the transport of merchandise, mainly by land, demonstrated in an international contest in which the members of this project participated. This fact promotes the interest of creating, adopting, and using traditional and original routing knowledge together with emerging classical and quantum technologies for use in real cases in the international industry. It is particularly interesting to examine a possible generalization of route optimization mechanisms from countries with different economic, geographic, and demographic characteristics, and their appropriate applicability in the national context of Uruguay.

A. Amazon's Last-Mile Routing Research Challenge, supported by the Massachusetts Institute of Technology (MIT).

Its main objective was the proposal to its participants for delineating, designing and applying efficient and innovative methods of sequencing stops using real data from 6125 routes from multiple cities, in order to automate decisions made by expert drivers.

The routes tend to be traveled using a tentative empirical order that depends on the specification of certain identifiers of certain groups of stops known as zones, delimited a priori by the hosts of the competition.

The sequences to be proposed should all start from an established initial stop (called a station) and use once all the stops destined for that route. Each of these routes also had an actual sequence used to compare the results.

Our research team participated with group name 'AlphaCentauri' and obtained an extremely competitive score on the final leaderboard.

II. Scope and Methodologies

A. Objectives

This project proposes customized methodologies to optimize cargo routing techniques in different contexts and geographical locations according to approaches based on classical adaptive technologies and with interesting emerging concepts of quantum computing. These methodologies receive as input multiple generated GPS data of delivery vehicles regularly recorded by delivery services and returns the proposed sequence of stops to optimize travel times, distances, and velocities to automate decisions made empirically by expert drivers. The complete procedure includes stages of multiobjective stops distinction, adaptable cost functions generation, dynamic stops clustering and segmentation together with identification and stops classification, and finally the predictive sequencing of delivery stops using combinations of learning methodologies and heuristics, apart from multiple approaches with quantum-inspired formulations and quantum annealers.
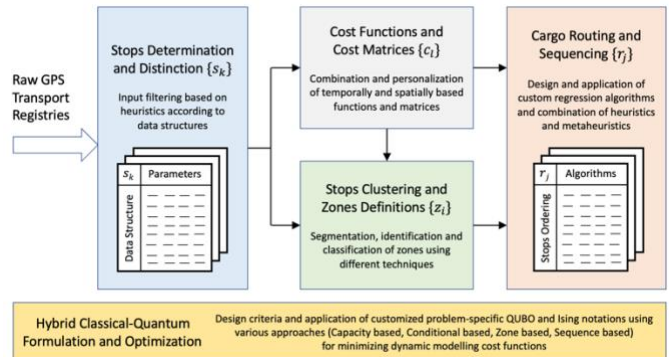

Fig. 1 Diagram of specific objectives of the master's thesis project.

These procedures expand, improve, and deepen the initial complex problem posed by the international competition LMRRC regarding delineating, designing, and applying efficient and innovative methods of sequencing stops. My research team participated in this international competition and qualified as a top-performing group due to its competitive obtained results.

B. Methods

Stops Preprocessing (SP): Multifunctional discrete optimization problem, approached by prioritized heuristics and constraints of

geographical location, driving distance, vehicle velocity and recorded events.

Stops Segmentation (SS): Clustering of stops using variations of agglomerative hierarchical clustering with convex-hull algorithms.

Zones Identification (ZI): Four-layered identification code assigned to each zone using pondered PCA vectors superpositions from a reference zone.

Stops Classification (SC): Stops assignment to zones based on their geometric silhouettes, geographic properties and relative locations.

Route Planning (RP): Dynamic selection of procedures of initial regression methods and then heuristics refinements based on route characteristics.

Classical-Quantum Computing (CQ): Design using QUBO Formulations with multiple approaches, and application using a Quantum Annealer platform.
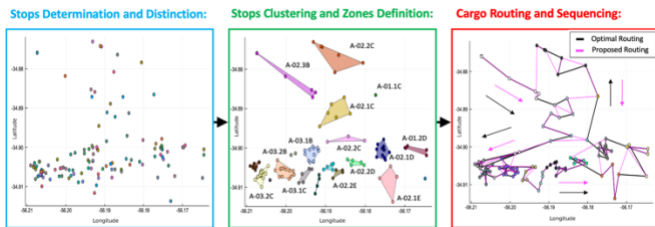

Fig. 2 Key flow passages proposed using a test last-mile route for central and peripheral areas in the city of Montevideo (Uruguay).

Refinement Considerations:

Zone Sequencing: Order of zones that remain unused from learning approach. Possibilities: Metric (Shortest Centroid Distance) or Set Distance (Minimum Hausdorff).

Stops Ordering: Sequence of stops inside a given cluster. Possibilities: Global exact based on Ford-Fulkerson model or Local stop-by-stop heuristics.

Transition Stops Definition: Determination of stops inbetween clusters. Possibilities: Last-Inner-Stop (last stop of current cluster is first stop of following cluster) or First-Outer-Stop (local approach between clusters for first stop of next cluster.).

Time Window Conditionals: Stops boost or delay in sequence based on time occurrence. Possibilites: Cluster or Route perspectives.

Capacity Limitations: Resupply transport at station based on load excess. Possibilities: Decision at cluster division or when detecting maximum saturation at a stop.
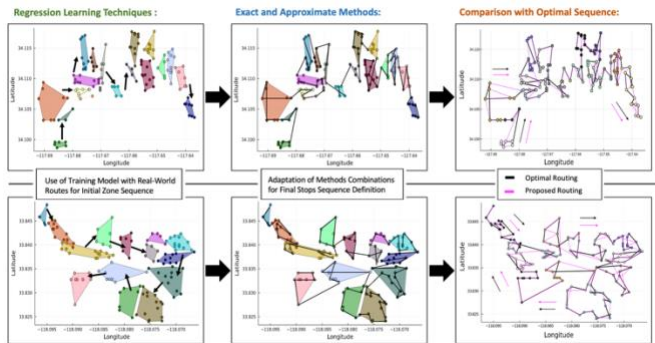

Fig. 3 Heuristics and learning approaches on the validation dataset, visualizing example route sequences with optimal and proposed routing.

II. Conclusions

A. Results

Stops Preprocessing: Detection of 108 stops per route on average. The results are limited to GPS precision and data recollection.

Dynamic Zones Analysis: Considerable variability of stops amount per zone. Adequate correlation of identification codes between routes.

Hybrid Classical-Quantum Route Planning: Reached an acceptable outcome, dependent on the amount of training routes and selected route characteristics.

TABLE I
AVERAGE RESULTS FOR EACH METHOD

	BOS	CHI	LA	SEA	MVD
True Pos % / False Pos % (SP)	23.5 / 4.3	21.2 / 4.8	22.3 / 4.6	17.3 / 5.2	15.8 / 5.3
V-Measure (SS)	0.742	0.747	0.776	0.787	0.798
Unicode Diff (ZI)	0.565	0.573	0.563	0.547	0.643
F-Score (SC)	0.828	0.823	0.857	0.865	0.835
R^2 Metric (RP)	0.779	0.793	0.787	0.764	0.739
R^2 Metric (CQ)	0.632	0.646	0.685	0.674	0.613

Average results by city: Boston, Chicago, Los Angeles, Seattle, Montevideo.
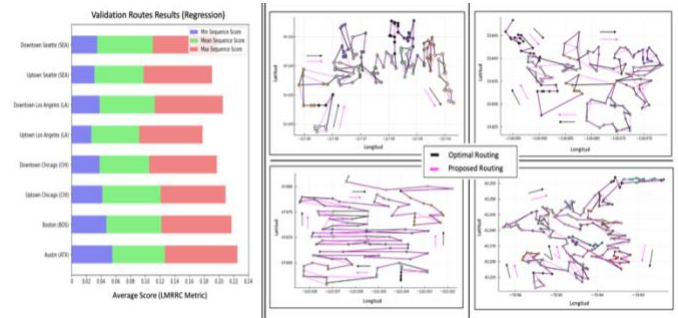

Fig. 4 Results of example routes together with regression results distinguished by city and area.

B. Final remarks

We presented a successful proposal of a representative workflow of an original methodology for the optimal tentative routing of stops from basic and geographic location records generated by delivery services. The complete procedure includes stages of detection of stops, prediction of zones and sequencing of deliveries used in thousands of routes. Also, this is a successful application of emerging hybrid classical-quantum techniques together with innovative model designs, and its applications on real-world routes from USA and Uruguay, particularly on cities of Boston, Chicago, Los Angeles, Seattle and Montevideo. Future contributions can be related to using similar approaches to other countries and transport means.

References

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