Optimizing Vehicle Routes and Planning for Water Treatment Maintenance Teams

CSE 4262 Final Project
Group 024: Yu J Chang, Cemil Ovacik, Lauren R Wilder, Finot Berhanu, Sebastian A Sanchez, & Sukriti Raut

Background

Gwinnett County Department of Water Resources is a utility in North Georgia that emphasizes the use of technology in improving maintenance methods and providing superior water service at an excellent value.

Motivation

The maintenance staff at Gwinnett County Department of Water Resources faces challenges such as overtime, project delay, and scheduling issues due to the lack of a data-driven scheduling system that optimizes routes, reduces technician overtime, and improves project timelines. This project focuses on building an interactive application powered by mathematical vehicle routing algorithms to provide the maintenance staff with optimized routes for their workday, ultimately saving time and improving efficiency in the maintenance of water treatment facilities.

Innovation

Our project comprises the following innovative elements:

- Centralized tool for pump station maintenance scheduling;
- Algorithmic diversity, various routing algorithms for flexible solutions;
- Work order priority prediction, aiding informed & efficient route planning;
- User-friendly design; future plans include automation.
- Performance evaluation of algorithm strengths/weaknesses

Approach

We created a solution for this problem by building the ‘Shortest Path’ web application, a centralized tool that generates optimized maintenance vehicle routes with the aid of vehicle routing and classification algorithms utilizing historic work order data.

Classification Algorithms

- Built supervised models using Dataset 2* to predict priority levels of work orders
- Class imbalance handled using over-sampling & under-sampling methods
- All models except KNN with original sample were optimized (hyper parameters tuned)

Models	Accuracy	Balanced Accuracy
K-nearest Neighbors W/ Original Sample (K=6)	0.94	0.55
K-nearest Neighbors W/ Under-sampling (Optimized)	0.62	0.62
K-nearest Neighbors W/ Over-sampling (Optimized)	0.66	0.66
Balanced Random Forest W/ Original Sample (Optimized)	0.87	0.54
Random Forest W/ Over-sampling (Optimized)	0.77	0.77

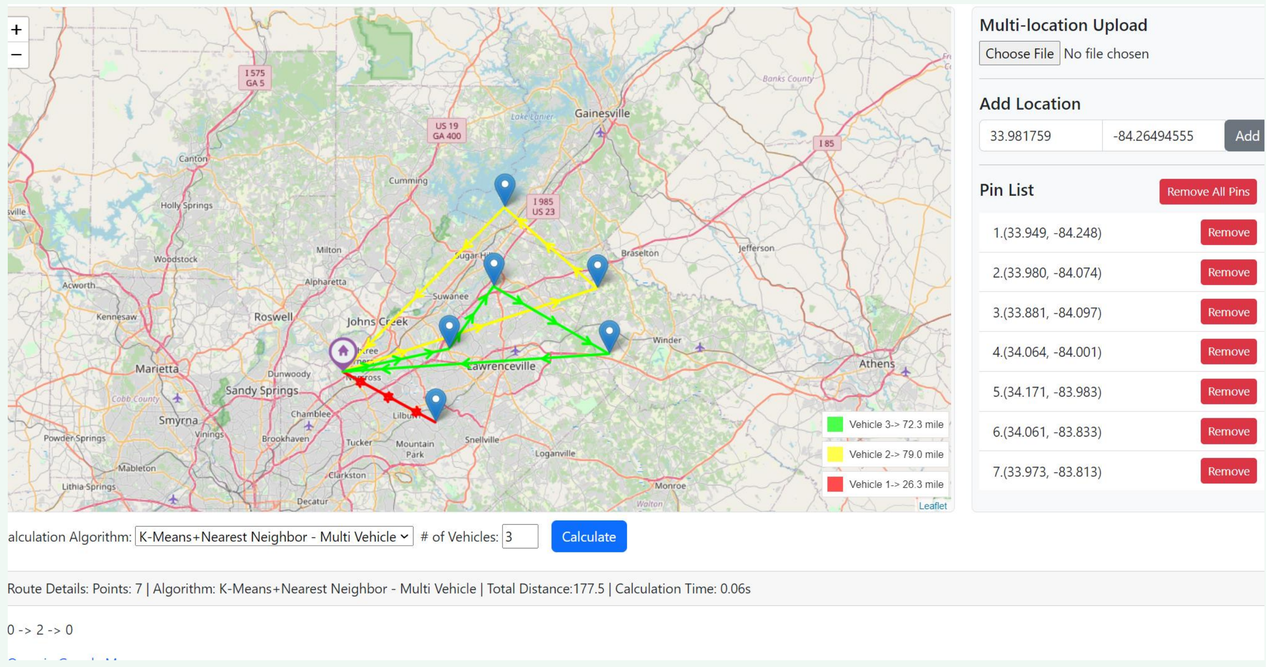
Vehicle Routing Algorithms

The following algorithms are available as options in the Shortest Path web app:

Algorithm	Description
Brute Force	Calculates the shortest route by computing total distances for all permutations of a given list of locations, determining the optimal path and calculating its duration.
Nearest Neighbor	Utilizes a precomputed distance matrix to identify the nearest unvisited location from a starting point and continues this process until all locations are visited, resulting in an optimized route.
Genetic Algorithm	Utilizes an iterative process involving population evaluation, selection of high-performing routes as 'parents,' crossover, mutation, and replacement to find the route with minimum distance.

Interactive Visualization

Our custom web app, Shortest Path, provides users with:
• An interactive map powered by Leaflet for accessibility across devices;
• User-friendly interface for inputting pump station locations and vehicle details;
• Marker functionalities for location management on the map;
• Generation of optimized vehicle routes, reducing resources for planning and travel time;
• Innovative solutions tailored to municipal facility maintenance, unmatched in the industry.



***Shortest Path* Web Application**

Data

Source: Gwinnett County Department of Water Resources maintenance management systems.

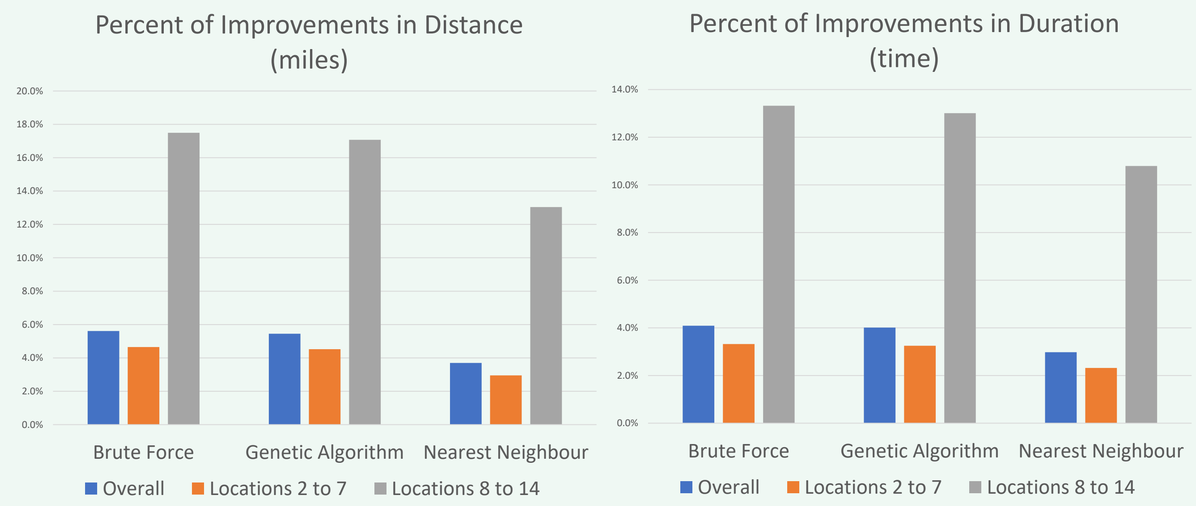
Characteristics:

- Dataset 1 - 23,000 rows, covering June 2021 – October 2023, detailing nature & location of pump stations visits.
- Dataset 2 – 320,000 rows (~40MB CSV), covering June 2021 – October 2023, detailing type, count, labor hours, labor cost, material cost, & total cost of work orders.

Evaluation

We employed a multi-faceted approach to evaluate the performance of the algorithms and models used in this project. They include:

Evaluation	Description
Comparative Analysis	Evaluating the performance of 3 routing algorithms (Brute Force, Nearest Neighbor, and Genetic Algorithm) to assess improvements in time and distance based on original or historical data.
Scalability Testing	Assessing algorithms' performance on varying numbers of locations to determine their scalability.
Accuracy Metrics	Utilizing accuracy metrics such as balanced accuracy, precision, recall, f-1 scores for K-Means and Random Forest to evaluate predictions.
Usability Feedback	Gathering feedback on the user-friendliness and efficiency of the web application "Shortest Path."



Results

Our experiments yielded the following reductions in duration and distance:

Results	Summary
Algorithm Performance	Brute Force exhibited the most significant improvement against original/historical data, followed closely by the Genetic Algorithm, and finally, the Nearest Neighbor Algorithm.
Improvement in Distance (%)	Significant improvements observed for routes with 8 or more locations: 13-17.5% reduction compared to baseline distances. For routes with 7 locations or less: 3-4.7% reduction.
Improvement in Duration (%)	Reduction in total duration by 10.8-13.3% for routes with 8 or more locations and 2.32-3.25% for routes with 7 or fewer locations.
Classification Algorithm Recommendation	Based on consistent accuracy & balanced accuracy of 77% and the highest precision, recall, and f-1 scores values, random forest fitted on over sampled data was utilized to predict work order priority levels.
VRP Algorithm Recommendation	Brute Force encounters performance issues after 9-10 locations. Therefore, the recommendation is to use Genetic Algorithm for an optimal route but Nearest Neighbor if efficiency is preferred.

Method Comparison

Our analysis and literature review indicate that our methods compare favorably to industry standards, effectively reducing travel distance, time, and costs, balancing accuracy and efficiency with optimal or heuristic solutions. The approach used in this project stands out further through its integration of various methods, including the use of mathematical vehicle routing algorithms, classification models, and a web application, making it a robust and versatile platform.