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ABSTRACT

This project developed a metaheuristic approach to the Multiple Traveling Salesman Problem that pairs a custom genetic algorithm with a conventional combinatorial optimization solver. This combined approach was used to build an optimal route for two popular radio show hosts to visit each of the 37 Atlanta area Jersey Mike's Subs in one day. This supported a fundraising effort to send children with chronic and terminal illnesses to Disney World through an organization called Bert's Big Adventure. Atlanta-area Jersey Mike's locations donated 100% of proceeds earned on this Day of Giving to Bert's Big Adventure. With the suggested route developed through our approach, the radio hosts successfully visited all 37 Jersey Mike's in one day, a task Bert's Big Adventure staff members had not been able to complete in previous years.

KEYWORDS

vehicle routing; genetic algorithm; multiple traveling salesman problem; combinatorial optimization; community action

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1. Introduction

The Bert Show is a popular morning show on Atlanta's Q99.7 radio station. They sponsor a non-profit organization, Bert's Big Adventure, that provides a "magical, all-expenses-paid, five-day journey to Walt Disney World for children with chronic and terminal illnesses and their families." On March 28th, 2018, 37 locations of Jersey Mike's Subs participated in their Jersey Mike's Day of Giving, donating 100% of sales in metro Atlanta to Bert's Big Adventure. As a promotional tie-in, the two hosts of the morning program wanted to visit each of these 37 locations on that day. Recognizing the distances involved and the difficult traffic conditions around the Atlanta metropolitan region, the Bert Show hosts made an on-air request for assistance in devising a pair of routes that would allow the hosts to visit each store by the end of the day. Our team of students and faculty from the Analytics and Data Science Institute at Kennesaw State University volunteered to solve this vehicle routing problem. The two main tasks of such a problem were: 1) optimally dividing the store locations into two sets, one for each radio host, and 2) determining the best route within each group of stores, accounting for store operating hours and metro Atlanta traffic patterns.

We developed a metaheuristic approach to the Multiple Traveling Salesman Problem (mTSP) that pairs a custom genetic algorithm (GA) with a conventional combinatorial optimization solver. The objective of the mTSP is to assign a tour of disjoint city sets to each of m salesman such that the maximum of the travel times for each salesman is minimized. In our program, the GA determines the assignment of cities to each radio host, while the combinatorial solver generates an optimal TSP route for each assignment. The maximum time for each single-TSP solution provides the cost function for the GA. The genetic algorithm provides an efficient search of the solution space and we show that this metaheuristic approach provides significant performance benefits over the use of the constrained combinatorial optimization solver alone.

In application, the route developed through our approach allowed the radio hosts to successfully visit all 37 area Jersey Mike's in one day. Bert's Big Adventure staff members had visited the stores during previous year's of the Day of Giving but had not been able to visit all of the Atlanta area stores in one day as stated in Bert Show (2018). The 2018 Jersey Mike's Day of Giving raised 27% more in donations than previous years, as stated in the Bert Show (2018), totalling $165,557 as reported by Jersey Mike's (2018).

2. Literature Review

One of the most widely known and extensively studied combinatorial optimization is Multiple Traveling Salesman Problem (mTSP). The classical definition of mTSP is defined as: Given n nodes and m salesmen starting at the central depot, find the best tours for all m salesman such that all nodes are visited exactly once and the total cost/length of all the tours are minimized. The mTSP has wide applications including school bus routing problem as discussed in Angel et al. (1972), interview scheduling problem studied by Gilbert and Hofstra (1992), design of global navigation satellite system surveying networks investigated by Saleh and Chelouah (2004) and so on. A more comprehensive review on different applications of mTSP can be found in papers by Wang and Regan (2002) and Macharis and Bontekoning (2004).

The mTSP is a well-known NP-hard problem and can be formulated as an integer program (IP). Laporte and Nobert (1980) proposed the first IP algorithm to solve mTSP. Their algorithm consists of relaxing the Subtour Elimination Constraint (SECs) in IP formulation to find the integer solution and then check for whether the SECs have been violated or not. Other researchers have also studied different variations of branch-and-bound approaches to solve mTSP.

The computational effort of exact algorithm grows exponentially as the network size of the mTSP increases. A need for better balance between computational effort and solution accuracy has led to development of heuristic solutions. One of the first heuristics in this area is due to Russell (1977). As found in our formulation, other metaheuristics such as evolutionary algorithm (EA), Tabu Search (TS), and Genetic Algorithm (GA) have been used to solve mTSP. The key idea behind these heuristics is that once a feasible solution has been constructed, an improvement heuristic can be applied to further improve the quality of the solution.

Other variations of mTSP include mTSP with time windows (mTSPTW) when some nodes in the network need to be visited in a particular time periods that are called time window. Aircraft scheduling problems are a perfect example of mTSPTW (Macharis et al. , 2004). Recently, researchers Othon and Spirakis (2016) have also studied dynamic TSP where problems are defined on temporal graphs where the graph changes with time.

The mTSP is generally regarded as a relaxed vehicle routing problem (VRP) since there is no restrictions on vehicle capacity. In general, VRP is concerned with designing optimal route and efficient strategies for a set of vehicles to meet customer requests, given some service constraints. It is widely used in supply chain management where a physical deliver of good or services are required. As Mole et al. (1983) pointed out mTSP can be utilized to solve several types of VRP problems. Excellent surveys on VRP can be found in Laporte (1992) and Laporte (2002).

Recently, Dynamic Vehicle Routing Problem (DVRP) has gained increased attention due to the advances in information technology. Real-time traffic information can be incorporated in to VRP to generate more efficient and practical solutions. Kim (2016) studies DVRP with non-stationary stochastic travel times under traffic congestion, and proposed a Markov decision process model to solve this problem. They also investigated how to estimate the probability distribution of travel times on the path that consists of multiple road segments.

Our focus in this paper involves the new application of Genetic Algorithm to solve a modified version of mTSP (m=2) for Bert's Big Adventure charity fundraising event.

3. Methods

This problem has two components to optimize: first, it must determine the best way to split the set of 37 locations into two relatively balanced sets for each radio host. Second, the locations should be placed in order as to minimize total drive time while visiting every location, also known as a TSP. To generate a pair of quick upper bounds on time, the team implemented splits via Euclidean distance and suggestions by long-time Atlanta residents (manual guidance). Assuming that the hosts would spend ten minutes at each stop, the total route times shown in Table1 were generated.

Table 1. Clustering analysis

Clustering Method	Predicted Drive Time	Estimated Total Time
Manual guidance	6hr48m	9hr24m
Euclidean distance	8hr54m	12hr36m

Given these worst-case times, we were confident that a feasible solution could be found using the genetic algorithm metaheuristic.

3.1. GeneticAlgorithm

As specified, the radio hosts routing problem is a variant of mTSP that seeks to minimize the maximum of the travel times for each vehicle, as opposed to minimizing the overall travel time (as is conventional). Our approach was two-phased: optimally divide the store locations into two sets, one for each radio host; and then determine the best route within each group of stores. Both phases would be impacted by store operating hours and metro Atlanta traffic patterns.

In our implementation, a genetic algorithm (GA) determines the assignment of cities to each radio host, while a combinatorial optimization solver generates an optimal TSP route for each assignment. The maximum time for each single-TSP solution provides the cost function for the GA. The genetic algorithm provides an efficient search of the solution space and we found that this metaheuristic approach provided significant performance benefits over the use of the constrained combinatorial optimization solver alone.

The metaheuristic approach taken here is attractive in that there is no need to tune the genetic algorithm for solving the Traveling Salesman Problem, as in other similar implementations, such as Grefenstette et al (1985). To solve an m salesman, n city problem, the genome for each individual in the GA population is simply a vector of n integers in the set $\{0 \ldots m-1\}$. In this fashion, the genome directly encodes the cities assigned to each salesman. However, at this point the ordering of the stops is not defined and is not encoded in the GA. Further, we assume that the starting point and ending point for each tour is the same for all travelers and is not included in the list of cities to visit.

As shown in Figure 1, our genetic algorithm performs the following steps:

(1) *Initialize Population*: A population of 20 individuals, defined by the genome are randomly created. Each genome is composed of 37 (number of stops) integers in the set {0,1} (representing each of the two radio hosts).

(2) *Evaluate Fitness*: The fitness of each individual in the population is scored by creating separate stop lists from the genome by mapping the genome indices by value. The weight matrix is precomputed using the drive times between all locations. Because there is no requirement for the drivers to return to the starting point (the *depot*), the return time to the depot is set to 0 for all stops. For our problem, this step greatly improved the solution. Next, each list is given to the constrained combinatorial optimization solver along with the depot node and the drive time matrix to find the best single TSP solution for that set of stops. The negative of the longer of the two solutions (in minutes) is returned as the evaluation score for that genome.

(3) *Survivor Selection*: With a fitness score assigned to each individual a selection strategy is chosen to provide the higher scoring individuals with a greater chance of being selected to contribute to the production of offspring. For this application, a *tournament selection strategy* was used, in which k individuals (in our case, 4) are chosen randomly from the population with the best two selected to act as parents for two new offspring. This selection process is repeated for each new individual in the next generation.

(4) *Crossover and Mutation*: Each succeeding generation is produced in place with complete replacement of the parent generation. Once a pair of individuals are selected to act as parents, those genomes are combined using a process called *crossover*. Our application used single-point crossover, where a single index point in the range $[1 \ldots 37]$ is selected as the crossover point. Two new individuals are created by swapping the portions of each genome on either side of the crossover point with the other.

    To aid in escaping from local minima, each newly-created genome is subject to random mutation. If a genome is selected for mutation, one, two, or three stops are randomly switched from one route to the other.

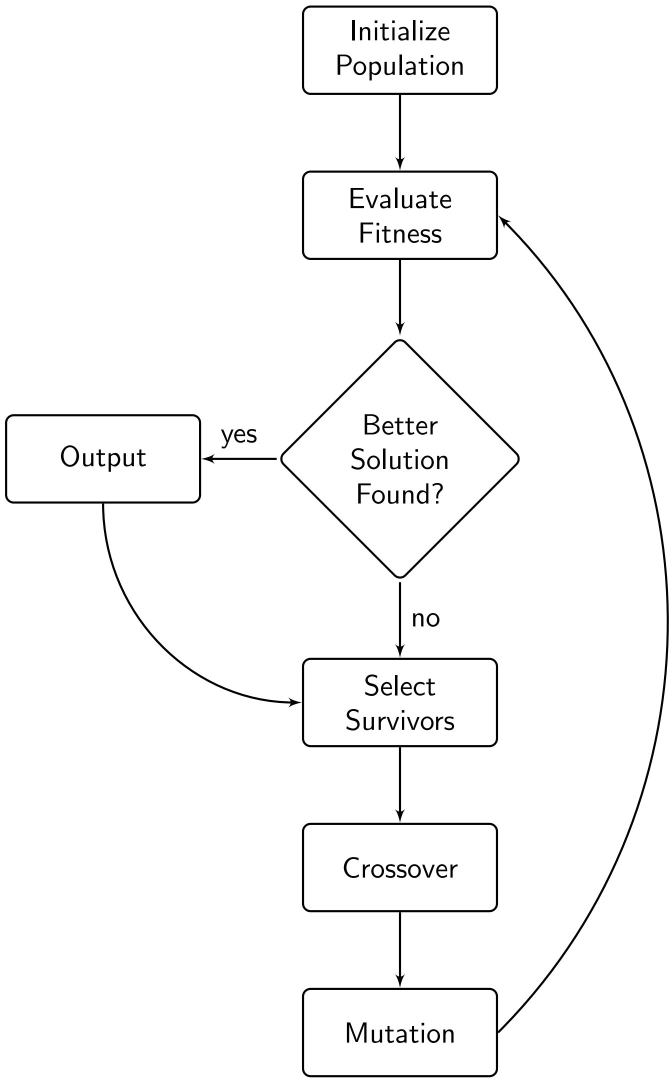

Figure 1. Genetic algorithm processing steps

3.2. Constrained Optimization Solver

For this application, we chose Google's OR-Tools library as our TSP solver, however most standard TSP solvers would suffice. The requirements for our application are that the solver accepts an unordered list of stops, a depot node, and a weight matrix. The solver returns the optimally-ordered single TSP solution and the time to complete the route.

4. Results

Our final solution used a metaheuristic approach that paired a custom genetic algorithm with a combinatorial optimization solver. This method produced an optimal solution in 900 generations, or approximately 15 minutes of run time. As shown in Table 2, the 37 locations were divided into 18 and 19 stops for the two hosts. Allotting ten minutes to spend at each location, we estimated that the longer of the two routes would take slightly under nine hours. With most Jersey Mike's opening at 10 AM and closing at 9 PM, we predicted that this solution would allow the two hosts to visit all thirty-seven restaurants in one business day. On March 28th, 2018 these two routes were completed ahead of schedule as seen in Table 2. Figure 2 shows the final routes presented as a promotional web page by the radio station.

Table 2. Predicted and actual route times

Host	Stops	Predicted Time	Actual Time
1	19	8hr51m	8hr15m
2	18	8hr33m	7hr22m

Figure 2. Final routes presented as promotional webpage

5. Conclusions and Future Work

The multiple traveling salesman class of problems are applicable to a variety of industries and functions. However, exact solutions become computationally expensive when the network size increases. Our metaheuristic approach, on the other hand, quickly produced an optimal solution that was successfully validated in a real-world application. The two radio show hosts visited each location within the predicted time and, along with Jersey Mike's, raised a record $165,557 for Bert's Big Adventure. Due to the success of the proposed route in 2018, Bert's Big Adventure is using the same route for the 2019 Day of Giving.

In this application, we were able to ignore the hourly changes in traffic patterns. However, future work will focus on factoring in those patterns and allowing the genetic algorithm to incorporate time windows into the exploration of the solution space.

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