MGSC662 Decision Analytics Final Group 9

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1 Introduction

Formula One (F1) is the world's premier automotive racing competition. Every year, the automotive industry's most distinguished manufacturers – in tandem with supremely talented drivers – vie for the most prestigious championship title in motorsport. In a given season, 21 races are staged at circuits located across the globe. Over the course of a season, teams travel around the globe.

While the history of F1 dates to 1950, the competition's global popularity has grown exponentially over the last 5 years. With increased popularity comes increased scrutiny, particularly in regard to how Formula One's operational procedures align with the public's growing insistence on ESG-conscious practices. Indeed, F1 would do well to be mindful of its environmental impact, given that international travel is at the core of its events; in a given season, 21 races are staged at circuits located across the globe. Travelling to each location entails transporting the massive amounts of equipment necessary for organizers to stage events and for teams to support their cars.

F1 claims ESG issues are of the utmost priority, having committed to net zero emissions by 2030. However, considering their total travel emissions in 2019 amounted to over 115,000 tonnes of CO2, it is the opinion of this team that further efforts can be made to lower F1's carbon footprint within a much shorter timeframe. As such, the purpose of this project is to generate an optimal schedule of races for the upcoming F1 season that minimizes carbon emissions from international travel. In order to generate a realistic and viable solution, constraints will be formed to account for important considerations such as financial profitability, fan satisfaction, and media exposure.

2 Problem Description and Formulation

2.1 Problem description and Scope

Considering current environmental challenges, we believe there should be more emphasis on lowering carbon emissions initially instead of heavily investing on carbon recycling solutions.

In this project, we focus on F1 races and aim to optimize the schedule to decrease the amount of emitted carbon dioxide caused by transportation between different circuits. We also keep in mind F1 as a business and try to optimize the schedule without lowering their revenues or fan's satisfaction. Therefore, we will build our optimization model to minimize carbon emission caused by F1 air transportations while maximizing their revenue from races and average fan ratings for the whole season.

To achieve this goal, we considered all 30 cities that have ever hosted an F1 race. We gathered revenue and average fan rating for all the races based on F1 public data. We also calculated the amount of emissions for all the possible routes between the cities based on ICAO and F1 public data. This part will be further explained in section 3.2.

To solve this problem, we proposed different approaches such as dividing it into two steps and using MIP to select the cities at the first stage and TSP to optimize the route, or utilizing VRP to solve the problem in a single stage. We will mainly focus on the first approach in this report but we will also discuss the second approach as well as an extension to this problem in section 4.

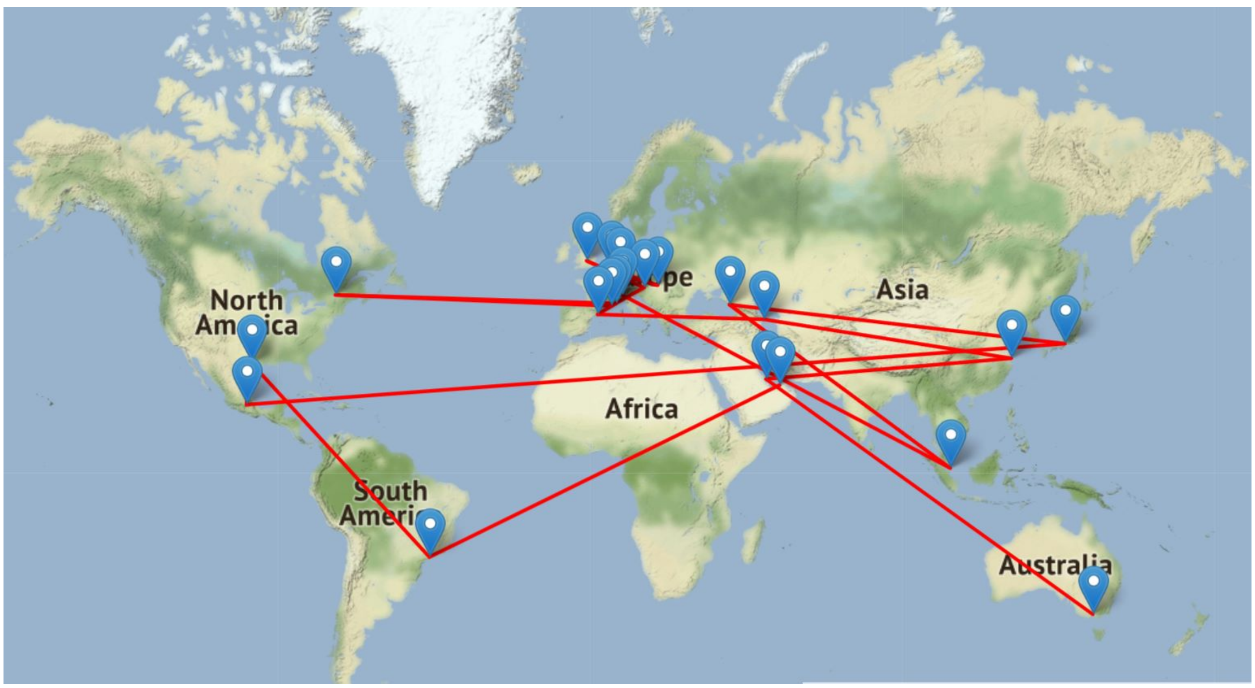

Figure 1: F1 Schedule Map Based on the Latest Public Data

2.2 Variable Description

2.2.1 Parameters

- $revenue_i$: F1 revenue from holding a race at city i.
- fan_i: Fan rating for the F1 race held in city i.
- $fuel_{ij}$: Amount of carbon dioxide emissions caused by traveling from city i to city j.

2.2.2 Decision Variables

The decision variables are different in our MIP model compared with the TSP step. In MIP, we aim to maximize revenue and fan ratings from all the races throughout the session at the same time. Therefore, we will define our decision variables as binary variables determining whether a city is selected to host a race or not. The following formulation demonstrates our decision variables for MIP:

$$X_i = \begin{cases} 1 & , \quad \text{city i is selected} \\ 0 & , \quad \text{otherwise} \end{cases}$$

$$i = (1,2,\ldots,30)$$

On the other hand, in TSP, we are aimed at minimizing the amount of emissions while transporting through different cities selected in MIP. Therefore, we will define our decision variables as binary variables determining whether a specific route is included in our solution or not. The following formulation demonstrates our decision variables for TSP:

$$X_{ij} = \begin{cases} 1 & , \quad \text{path from city i to city j is selected} \\ 0 & , \quad \text{otherwise} \end{cases}$$

$$i\ ,\ j = (1,2,\ldots,21)$$

$$U_i \in \mathbb{Z}\ ,\ \text{for}\ i = (1,2,\ldots,21) : \text{Dummy variable to break subtours}$$

We want to emphasis that X_{ij} is different from X_{ji} since in our case going from city i to city j would dramatically change the path in comparison with going from city j to city i.

2.3 Problem Formulation

2.3.1 Mixed-integer Programming (MIP)

We would like to select twenty two cities out of thirty in order to maximize both revenue and fan rating, so the objective function is to maximize:

$$\sum_{i=1}^{30} X_i \cdot revenue_i \cdot fan_i$$

Subject to:

(1.1)

$$\sum_{i=1}^{30} X_i = 21$$

(1.2)

$$\sum_{i=1}^{30} X_i \cdot revenue_i \geq 697$$

(1.3)

$$\sum_{i=1}^{30} X_i \cdot fan_i \geq 6.751$$

Constraint (1.1) limits the total number of races to twenty two, (1.2) ensures that the revenue is greater than the current revenue, (1.3) ensures the fan rating is greater than the current fan rating.

2.3.2 Travelling Salesman Problem (TSP)

Out of the 21 cities selected, we would like to find the optimal schedule for the season in order to minimize emissions. The objective function is to minimize:

$$\sum_{i=1}^{21} \sum_{j=1}^{21} X_{ij} \cdot fuel_{ij}$$

Subject to:

(1.1)

$$\sum_{i=1}^{21} X_{ij} = 1 \qquad \text{for } j = 1, ..., 21$$

(1.2)

$$\sum_{j=1}^{21} X_{ij} = 1 \qquad \text{for } i = 1, ..., 21$$

(1.3)

$$\sum_{i=1}^{21} X_{ii} = 0$$

(1.4)

$$U_i - U_j + 21 \cdot X_{ij} \leq 21 - 1 \qquad , 2 \leq i \neq j \leq 21$$

(1.5)

$$1 \leq U_i \leq 21 - 1 \qquad , 2 \leq i \leq 21$$

Constraint (1.1) ensures that the F1 tour may enter a city only once, (1.2) ensures that they may exit a city only once, (1.3) ensures that they can not travel from one city back to the same city. (1.4) and (1.5) are constraints on our dummy variables U_i in order to prevent subtours in our schedule.

3 Numerical Implementation and Results

3.1 Calculations and Parameter Estimation

To replicate the real-world situation, we needed to estimate some parameters according to changes in F1 schedule since they released their latest public data. Therefore, we estimated the values for total revenue and average fan rating for each race. In addition, F1 publishes their aggregate carbon footprint instead of dividing it by different races. Therefore, we utilized F1 public data in conjunction with ICAO data for different flights to calculate the amount of carbon dioxide emissions for each possible route.

3.1.1 Fan Rating

In addition to lowering the amount of carbon dioxide emissions, we considered F1 as a business in this project. Since no business wants to lower their customer satisfaction, we also wanted our solution not to negatively impact this metric. For this purpose, we considered average fan rating of the races as an indicator of customer satisfaction. According to the official data, the average fan rating for races throughout the season is 6.75. Therefore, we solved the problem subject to a minimum average fan rating of 6.75.

3.1.2 Revenue from Races

Although our primary goal in this project is to lower the amount of carbon emissions caused by air transport between different cities for F1 races, we keep in mind that F1 is also a business. So, we want our solution not to negatively impact F1 revenue from races. To achieve this goal, we relied on F1 official data about their contracts, which reveals their revenue from races in each circuit. According to the latest official data, F1 has made 697 million dollars of revenue from races. Hence, we solved the problem subject to a minimum revenue of 697 million dollars for the whole season.

3.1.3 Land Transportation for Close Cities

Since our main goal in this project is to lower the amount of emissions, we considered land transportation between two cities as well as aerial transport. Having in mind the significant difference between carbon emissions from land transport and air transport for close locations, we assumed transportation between cities of a distance of lower than 400 kilometers to be land transport.

3.2 Data Description

Our main source of data for this project is the latest public data from F1 as well as ICAO. The available F1 information includes data about carbon emissions as well as revenues and fan ratings for the 2019 season. It is worth mentioning that the official data only announces the overall carbon emissions not emissions per route. Therefore, we also utilized ICAO data to find the emissions for each possible path. To do so, we extracted the revenue and fan rating data for each city that has ever hosted an F1 race. Then, we used ICAO calculator to find the amount of emissions for routes between every two cities. It is worth mentioning that ICAO calculator presents the amount of fuel burnt for different routes whereas F1 data announces the amount of carbon emission. To address this issue, we utilized basic stoichiometry rules. According to this rule, since carbon emissions are a product of a chemical reaction between the fuel and oxygen, the amount of fuel burnt can be easily converted to carbon emissions using a scalar. Therefore, we formed the 30 by 30 matrix that each of its ij elements represents the amount of fuel burnt to travel from city i to city j. Having this matrix formed, we calculated the scalar by comparing the emissions amount reported by F1 and the aggregate fuel burnt amount, according to ICAO, for the same route. It enabled us to scale the whole fuel burnt matrix to carbon emissions matrix for all the possible routes.

3.3 Results

The model was formulated using Python v3.8 and Gurobi v9.5. As mentioned earlier, we modeled the problem in two stages.

At the first stage, we managed to simultaneously maximize F1's total revenue and the average fan rating of the races for the whole season subject to a minimum revenue of 679 million dollars and a minimum average fan rating of 6.75. For this purpose, we defined 30 decision variables each representing whether a city is going to host an F1 race. For the sake of comparability, we kept to total number of selected cities equal to 21, which is the number of races for the latest season which its official data is public. According to the results we managed to select 21 cities (out of the 30 possibilities) by not holding a race in Barcelona, Bologna, Brussels, Graz, Las Vegas, Marseille, Mexico City, Nagoya, and Nice. The total revenue and average fan rating is 791 million dollars and 6.83 respectively.

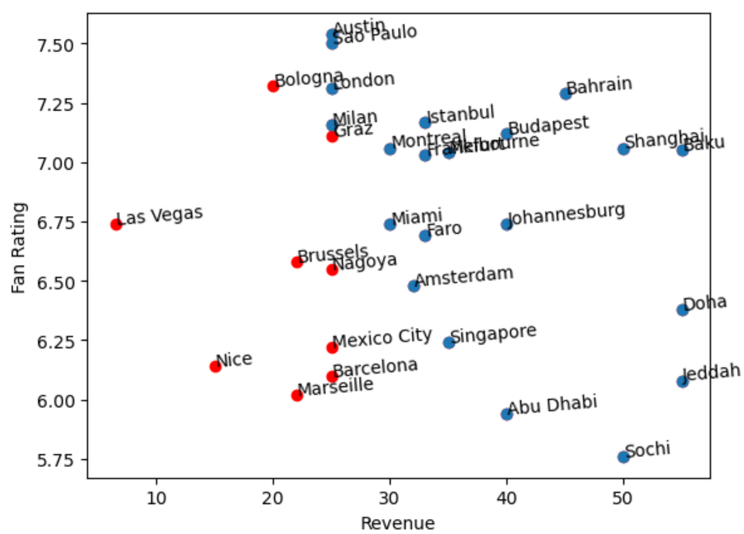

Figure 2: 21 Cities(blue) Selected for TSP

Having selected the cities, we moved to optimizing the route using TSP. For this purpose, we defined 870 new decision variables representing all the possible routes between each two cities. To avoid sub-tours in our final solution, we also introduced 29 dummy variables to our model. We solved this problem subject to entering and exiting all the cities only once. It should be mentioned that we cannot enter the city that we have just left in a Traveling Salesman Problem. Sub-tour elimination constraints were also introduced into the model according to Miller-Tucker-Zemlin reformulation. Solving this model, we managed to lower the carbon emissions to 48.6 million kilograms, which shows more than 57 percent of decrease in comparison to the officially announced amount of 115.4 million kilograms. The following table demonstrates the optimal route for this problem:

From	To
Abu Dhabi	Baku
Baku	Sochi
Sochi	Istanbul
Istanbul	Budapest
Budapest	Milan
Milan	Frankfurt
Frankfurt	Amsterdam
Amsterdam	London
London	Faro
Faro	Sao Paulo
Sao Paulo	Montreal
Montreal	Miami
Miami	Austin
Austin	Shanghai
Shanghai	Melbourne
Melbourne	Singapore
Singapore	Johannesburg
Johannesburg	Jeddah
Jeddah	Bahrain
Bahrain	Doha

Figure 3: Final Schedule

4 Problem Extensions

4.1 Vehicle Routing Problem (VRP)

We introduce N, a numberic index of each city from 1:30. We also introduce V, which is $N \cup \{0\}$. We introduce Q = 21 as the total number of cities in our subtour and $q_i \in \mathbb{Z}$ as a counter for cities visited. Similarly to the traveling salesman problem, the objective function of VRP is to minimize:

$$\sum_{i=1}^{30} \sum_{j=1}^{30} X_{ij} \cdot fuel_{ij}$$

Subject to:

(1.1)

$$\sum_{i \in V} X_{ij} = 1 \qquad \text{for } j \in N$$

(1.2)

$$\sum_{j \in V} X_{ij} = 1 \qquad \text{for } i \in N$$

(1.3)

$$\sum_{j \in V} \sum_{j \in V} U_i + q_i = U_j \qquad \text{for } X_{ij} = 1 \text{ and } i, j \neq 0$$

(1.4)

$$U_i \geq q_i \qquad \text{for } i \in N$$

(1.5)

$$U_i \leq Q \qquad \text{for } i \in N$$

Constraints (1.1) and (1.2) ensure that each city is only entered and exited one time. Constraint (1.3) is very similar to the MTZ constraint but it is different for each race count of q_i. Constraints (1.4) and (1.5) ensure that the MTZ dummy variable U_i is always greater than the count of q_i, and always less than the total number of races Q_i.

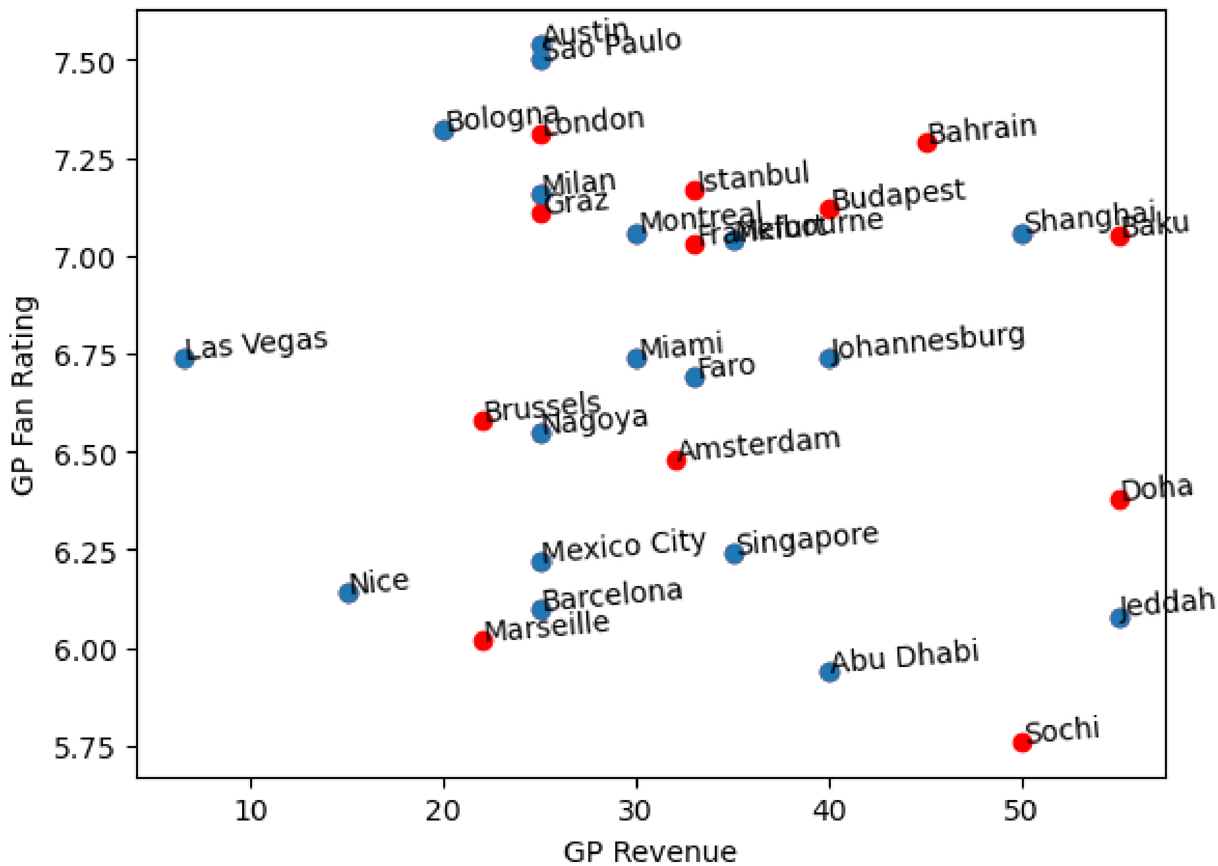

Figure 4: 21 Cities(blue) Selected for VRP

5 Conclusion

In addition to revenues and fan ratings, the F1 schedule is also susceptible to other parameters such as weather, time of the day, etc. For example, we may never see an F1 race in Montreal during winter because of the weather. These considerations might alter the applicability of our solution in practice because we have not taken seasonality or weather data into consideration due to the complexity of weather forecasting for such a long period of time. On the other hand, Monaco Grand Prix has been held every year throughout F1 history and is a figure race. Therefore, we cannot imagine they give up on holding a race at Nice whereas it is not present in our solution for the sake of maximizing the revenue and fan rating.

Figure 5: VRP Schedule Map

Although our model suggests a solution for significantly reducing carbon emissions while increasing revenues and the average fan rating, the main limitation of our model is solving the problem in two stages. It might cause problems since revenue maximization is not the main goal. In the best-case scenario, minimizing carbon emissions subject to a minimum revenue and average fan rating should be done in a single stage. To address this issue, we tried to frame the problem as a Vehicle Routing Problem (VRP) as discussed in section 4.1. However, we cannot ensure that the solution from VRP is the optimal solution for our problem even though VRP is NP-complete. The reason for this uncertainty is that, in VRP, the vehicle is supposed to visit all the existing nodes. In our case, it means all the cities have to be included in one of the sub-tours. However, in our problem, only the selected cities have to be visited and it does not matter whether the rest of the nodes will be covered. In other words, VRP would definitely minimize the amount of emission considering that all 30 possible cities are covered. As a result, it might not minimize the emissions for the sub-tour of 21, which is the goal of this project, for the sake of minimizing the total emissions for all 30 cities.

Constantly decreasing the amount of carbon emissions is critical according to climate change. Although our solution lowers emissions by more than 57 percent, we believe further work on this topic is required. For cases similar to our use case that try to minimize transportation costs for m out of n possibilities (m¡n), we suggest considering framing the problem as a Rural Postman Problem. RPP is a subset of the Chinese Postman Problem (CPP) - which itself is a subset of VRP – that does not necessarily cover all the possible nodes within the graph. Therefore, it will not compromise on the optimality of the desired sub-tour for the sake of optimizing the whole tour. RPP is also an NP-complete solution.

In conclusion, our model, aimed at lowering carbon emissions subject to a minimum revenue and average fan rating for F1, considerably decreases the emissions. Also, the model is flexible for changing the number of selected nodes or possibilities. Therefore, it can be used not only for optimizing the schedule for prospective F1 seasons but also for solving any problem that aims to minimize the transportation cost for a graph consisting of n nodes while not necessarily covering all the nodes, such as unbalanced supply chain networks.

References

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2. *F1 Logistics Information (2022)*
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4. *Fan Rating Data (2016)*