Application of Greedy Algorithm to Find the Shortest Flight Route For the 2022-23 Formula E Calendar

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***Abstract*— Formula E is currently the most popular and well-known electric vehicle motorsport championship. Established in 2014, the series has attracted lots of people with its intention to commercialize more environmental-friendly electric vehicles to the public. Despite the series being able to achieve net zero since its inception, the traveling is still not, as the teams, drivers, and officials are traveling through the world by using planes; which is still not that environmental-friendly. This paper is written with the intention to analyze the shortest possible route for planes to be used throughout a Formula E season.**

Keywords— Formula E, Greedy, Route, Distance

I. Introduction

Figure 1.1. Formula E cars racing at Mexico City E-Prix.
(Source: https://capetowneprix.com/formula-e-season-9-race-report-jake-dennis-wins-first-race-of-the-gen3-era-in-mexico/)

Formula E is a single-seater motorsport championship for electric cars that made its debut back in 2014. The idea of Formula E was conceived by the president of Fédération Internationale de l'Automobile (FIA) at that time, Jean Todt. Jean Todt presented the idea of a single-seater electric car racing to politicians Alejandro Agag and Antonio Tajani while having dinner in Paris in 2011. Agag agrees with the idea and decides to be the CEO of Formula E since its inauguration up until 2019.

Figure 1.2. Alejandro Agag
(Source:https://www.mwcbarcelona.com/agenda/speaker/alejandro-agag)

In an interview conducted by Current E, Alejandro Agag believes that with the world quickly transitioning from fossil fuels into an eco-friendly alternative in such a short span of time, Formula E takes benefit from all of it in the world of motorsports. “The motor industry is going in three directions: electric, connected, and driverless. Formula E is electric. Fine. We have to be more connected.” Agag said. Later in that interview, Agag states that Formula E wants to contribute to bringing the importance of renewable fuel in today’s society, “This championship is promoting technology that is clean and that is helping to fight pollution and climate change,” Agag states.

The amount of Formula E viewers has been on the rise, with 2022 statistics showing 381 million cumulative audiences with live viewership growing to an all-time high of 216 million. And with new fans coming to the sport, there have been a lot of concerns related to Formula E’s green credentials, as the sport flies to different cities around the world with planes, which leaves a lot of carbon footprint which isn’t environmentally friendly.

II. Greedy Algorithm

Greedy algorithm is the simplest and the most popular method to solve optimization problems, that is to find the optimal solution of a problem.

For the definition itself, greedy algorithm is an algorithm that solves problems step by step, so that for each step:

1. Takes the best possible option at that time without looking at consequences forward ("take what you can get now!"),
2. And "hoping" that by picking the local optimum for each step, it'll end with the global optimum.

Greedy algorithm elements are as follows:

1. Candidate set, C: Contains all candidates that will be chosen for each step.
2. Solution set, S: Contains every candidate that has been selected.
3. Solution function: Determines if the chosen candidate set is already giving a solution.
4. Selection function: Choose a candidate based on a certain greedy strategy (heuristic).
5. Feasible: Checks if the chosen candidate can be inserted into the solution set.
6. Objective function: Maximize/minimize.

There is a warning in greedy algorithm, which is the fact that the global optimum solution isn't always the optimum solution, that's because greedy algorithm didn't fully operate into every possible solution and there are several different selection functions, in which we need to pick the right function if we want the algorithm to find the optimal solution.

So, in several cases, the greedy algorithm fails to give the optimal solution. For example, let's check the coin exchange problem, where a person has an unlimited amount of coins with a certain value, and that person needs to exchange an amount of X value with the least amount of coins that person has. Suppose a person has coins with the value of 5, 4, 3, and 1. The person wants to exchange 7 with the coins available. With the greedy algorithm, the first step is to choose a coin with a value of 5 (as it is the coin with the most value and is still below 7), and the next step is to choose a coin with a value of 1 (as 5+5, 5+4, and 5+3 are already above 8), and the last step is to choose 1 again, making it 5+1+1 = 7. This isn't optimal as it requires 3 coins to do the exchange, the optimal solution is by using coins with the value of 4 and 3 (4+3 = 7), which only requires 2 coins instead of 3.

If the absolute best solution isn't too necessary, that means a greedy algorithm can be used to find an approximation solution, instead of using an algorithm that requires an exponential amount of time to generate the exact result. For example, finding a path with the minimum weight at TSP cases for a large number of nodes, it'll take a lot of time to compute the result if we use a brute force algorithm. With greedy, even if the minimum weight cannot be found, it is still possible to find the optimal approximation result. But if a greedy algorithm is able to generate an optimal solution, then the optimization must be mathematically proven. Mathematically proving the optimality of greedy algorithms is a challenge in itself. It is easier to show that a greedy algorithm isn't always optimal by showing the counterexample, like in the coin exchange problem above.

Examples of problems that can be solved with greedy algorithm:

1. Coin exchange problem
2. Activity selection problem
3. Minimize time in system
4. Knapsack problem
5. Job scheduling with deadlines
6. Minimum spanning tree
7. Shortest path
8. Huffman code
9. Egyptian fraction

III. CALENDAR

The 2022-2023 season calendar can be seen in the image below.

Figure 3.1. Formula E 2022-2023 (Season 9) calendar. (Source: https://www.sportstravelmagazine.com/portland-to-host-formula-e-world-championship-race-in-2023/)

There are 16 rounds of Formula E racing for this season, with some rounds being held in the same city twice. The form of this season's calendar in the table looks like this:

Table I. Formula E 2022-2023 calendar in table format.

Round	City, Country
1	Mexico City, Mexico
2-3	Diriyah, Saudi Arabia
4	Hyderabad, India
5	Cape Town, South Africa
6	São Paulo, Brazil
7-8	Berlin, Germany
9	Monaco, Monaco
10-11	Jakarta, Indonesia
12	Portland, USA
13-14	Rome, Italy
15-16	London, UK

As you can see from the table above, there are several routes that are deemed too inefficient. One example is the route Mexico → Saudi Arabia → India → South Africa → Brazil, it is inefficient since the route requires everyone to fly across the Atlantic Ocean from Mexico to Saudi Arabia, a

long flight from India to South Africa, and then another fly above the Atlantic Ocean to Brazil.

In the next chapter, I'll try to find the shortest flight route for the 2022-2023 (season 9) Formula E calendar using greedy algorithm.

IV. Finding the Shortest Flight Route

All of the nodes will be represented by airports near the racing circuit, which are as follows:

Table II. Airports for each node at every city.

City, Country	Airport
Mexico City, Mexico	Mexico City International Airport
Diriyah, Saudi Arabia	King Khalid International Airport
Hyderabad, India	Rajiv Gandhi International Airport
Cape Town, South Africa	Cape Town International Airport
São Paulo, Brazil	Aeroporto Internacional de São Paulo
Berlin, Germany	Berlin Brandenburg Airport
Monaco, Monaco	Nice Côte d'Azur Airport
Jakarta, Indonesia	Soekarno-Hatta International Airport
Portland, USA	Portland International Airport
Rome, Italy	Leonardo da Vinci International Airport
London, UK	Heathrow Airport

If we visualize the route on Google Maps, then the route will look like this:

Figure 4.1. Formula E 2022-2023 (Season 9) calendar route visualized on Google Maps.
(Source: Local library)

And the overall distance is:

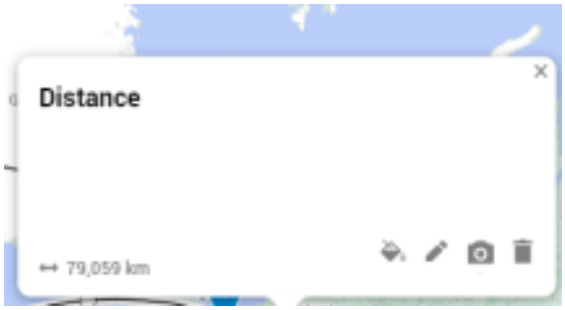

Figure 4.2. Formula E 2022-2023 (Season 9) calendar route total distance calculated.
(Source: Local library)

It can be seen from the picture above, the flight distance from the beginning of the season at Mexico City, to the final round at London, took roughly 79,059 km of traveling, almost the twice earth's circumference.

There are lots of algorithms that can be used to find the shortest path, but for this paper, we will use greedy algorithm. The application of the greedy algorithm will be explained below.

A. Pick a starting point

We will start the algorithm with Mexico City as the starting point, so that we can compare the greedy algorithm's final distance to the current calendar's distance.

B. Mexico City

Using *Google Maps*, these are the distance from Mexico City International Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table III. Distance of every airports from Mexico City International Airport.

Airport	Distance (KM)
Portland International Airport	3,625
Aeroporto Internacional de São Paulo	7,441
Heathrow Airport	8,914
Berlin Brandenburg Airport	9,748
Nice Côte d'Azur Airport	9,774
Leonardo da Vinci International Airport	10,234
Cape Town International Airport	13,727
King Khalid International Airport	13,860
Rajiv Gandhi International Airport	15,946
Soekarno-Hatta International Airport	16,884

From Table III, it can be seen that Portland International Airport is the nearest airport from Mexico City. Therefore, the updated route now is = Mexico City → Portland.

C. Portland

Starting from this step onwards, the algorithm/ways to find the shortest path will be no different compared to finding path in point B; search all distances from airport *X* to another airport that hasn't been visited, take the airport with the shortest distance, connect it with the existing path.

These are the distance from Portland International Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table IV. Distance of every airports that haven't been visited from Portland International Airport.

Airport	Distance (KM)
Heathrow Airport	7,895
Berlin Brandenburg Airport	8,356
Nice Côte d'Azur Airport	8,935
Leonardo da Vinci International Airport	9,327
Aeroporto Internacional de São Paulo	10,850
King Khalid International Airport	12,110
Rajiv Gandhi International Airport	12,728
Soekarno-Hatta International Airport	13,585
Cape Town International Airport	16,516

From Table IV, it can be seen that Heathrow Airport is the nearest airport from Portland. Therefore, the updated route now is = Mexico City → Portland → London.

D. London

These are the distance from Heathrow Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table V. Distance of every airports that haven't been visited from Heathrow Airport.

Airport	Distance (KM)
Berlin Brandenburg Airport	962
Nice Côte d'Azur Airport	1,042
Leonardo da Vinci International Airport	1,445
King Khalid International Airport	4,946
Rajiv Gandhi International Airport	7,762
Aeroporto Internacional de São Paulo	9,471
Cape Town International Airport	9,692
Soekarno-Hatta International Airport	11,734

From Table V, it can be seen that Berlin Brandenburg Airport is the nearest airport from London. Therefore, the updated route now is = Mexico City → Portland → London → Berlin.

E. Berlin

These are the distance from Berlin Brandenburg Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table VI. Distance of every airports that haven't been visited from Berlin Brandenburg Airport.

Airport	Distance (KM)
Nice Côte d'Azur Airport	1,075
Leonardo da Vinci International Airport	1,179
King Khalid International Airport	4,131
Rajiv Gandhi International Airport	6,812
Cape Town International Airport	9,624
Aeroporto Internacional de São Paulo	10,239
Soekarno-Hatta International Airport	10,772

From Table VI, it can be seen that Nice Côte d'Azur Airport is the nearest airport from Berlin. Therefore, the updated route now is = Mexico City → Portland → London → Berlin → Monaco.

F. Monaco

These are the distance from Nice Côte d'Azur Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table VII. Distance of every airports that haven't been visited from Nice Côte d'Azur Airport.

Airport	Distance (KM)
Leonardo da Vinci International Airport	461
King Khalid International Airport	4,131
Rajiv Gandhi International Airport	7,204
Cape Town International Airport	8,719
Aeroporto Internacional de São Paulo	9,261
Soekarno-Hatta International Airport	11,249

From Table VII, it can be seen that Leonardo da Vinci International Airport is the nearest airport from Monaco. Therefore, the updated route now is = Mexico City → Portland → London → Berlin → Monaco → Rome.

G. Rome

These are the distance from Leonardo da Vinci International Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table VIII. Distance of every airports that haven't been visited from Leonardo da Vinci International Airport.

Airport	Distance (KM)
King Khalid International Airport	3,675
Rajiv Gandhi International Airport	6,788
Cape Town International Airport	8,460
Aeroporto Internacional de São Paulo	9,444
Soekarno-Hatta International Airport	10,838

From Table VIII, it can be seen that King Khalid International Airport is the nearest airport from Rome.

Therefore, the updated route now is = Mexico City → Portland → London → Berlin → Monaco → Rome → Diriyah.

H. Diriyah

These are the distance from King Khalid International Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table IX. Distance of every airports that haven't been visited from King Khalid International Airport.

Airport	Distance (KM)
Rajiv Gandhi International Airport	3,396
Cape Town International Airport	7,202
Soekarno-Hatta International Airport	7,350
Aeroporto Internacional de São Paulo	11,393

From Table IX, it can be seen that Rajiv Gandhi International Airport is the nearest airport from Diriyah. Therefore, the updated route now is = Mexico City → Portland → London → Berlin → Monaco → Rome → Diriyah → Hyderabad.

I. Hyderabad

These are the distance from Rajiv Gandhi International Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table X. Distance of every airports that haven't been visited from Rajiv Gandhi International Airport.

Airport	Distance (KM)
Soekarno-Hatta International Airport	4,050
Cape Town International Airport	8,522
Aeroporto Internacional de São Paulo	14,278

From Table X, it can be seen that Soekarno-Hatta International Airport is the nearest airport from Hyderabad. Therefore, the updated route now is Mexico City → Portland → London → Berlin → Monaco → Rome → Diriyah → Hyderabad → Jakarta.

J. Jakarta

These are the distance from Soekarno-Hatta International Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table XI. Distance of every airports that haven't been visited from Soekarno-Hatta International Airport.

Airport	Distance (KM)
Cape Town International Airport	9,459
Aeroporto Internacional de São Paulo	15,638

From Table XI, it can be seen that Cape Town International Airport is the nearest airport from Jakarta. Therefore, the updated route now is = Mexico City → Portland → London → Berlin → Monaco → Rome → Diriyah → Hyderabad → Jakarta → Cape Town.

K. Cape Town

These are the distance from Cape Town International Airport to the other cities' airports (excluding airports that have been visited), ordered from nearest to furthest:

Table XII. Distance of every airports that haven't been visited from Cape Town International Airport.

Airport	Distance (KM)
Aeroporto Internacional de São Paulo	6,359

Since there's only one unvisited airport left departing from Cape Town, that is São Paulo, the next destination will automatically be São Paulo. Therefore, the updated route now is = Mexico City → Portland → London → Berlin → Monaco → Rome → Diriyah → Hyderabad → Jakarta → Cape Town → São Paulo.

L. São Paulo

There are no more unvisited airports after São Paulo, which means the searching algorithm is now done. The final route is = **Mexico City → Portland → London → Berlin → Monaco → Rome → Diriyah → Hyderabad → Jakarta → Cape Town → São Paulo.**

V. CONCLUSION

After implementing greedy algorithm for the Formula E calendar showed earlier in the paper, this is how the route looks.

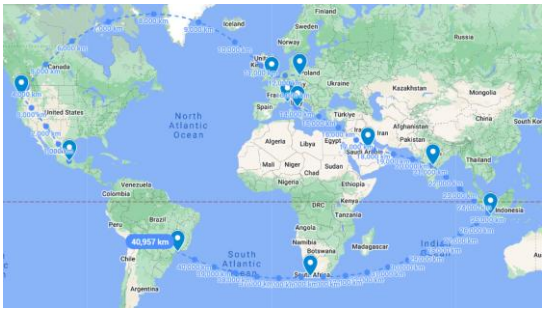

Figure 5.1. Formula E 2022-2023 (Season 9) new route visualized on Google Maps along with its distance. (Source: Local library)

It can be seen from the map above that the distance after implementing the greedy algorithm into the calendar is now only 40,957 km. To calculate the efficiency between greedy algorithm's route and the original's route, we can easily subtract the original distance from the new distance, divided

by the original distance, and then multiply it by 100%.

$$\frac{(79059 - 40957)}{79059} * 100\% = 48.2\%$$

Figure 5.2. Greedy algorithm route's efficiency compared to the original route.
(Source: Local library)

The greedy algorithm's route brings 48.2% efficiency compared to the original route. Despite a large amount of distance being slashed off from the original route, it's hard to determine if the new distance is the optimal one or not, as I said before in the second chapter, sometimes greedy algorithm fails to give the optimal solution since it only looks for the next step instead of the overall solution.

It is also important to note that all of the route distances above is assuming that the flight doesn't get interrupted by bad weather or any other situation that forces the plane to take some time in the sky, therefore releasing more carbon footprint.

All of that aside, the greedy algorithm above is a good example of how there's a better flight route for the Formula E calendar so that everyone is able to take less flight time, and makes the sport becoming more environmentally friendly.

Video Link At YouTube

https://youtu.be/ZndozP0x5nc

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PERNYATAAN

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Bandung, 22 Mei 2023

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