Hamilton Waterfall Tours: Connecting Nature and Transit

Table of Contents

1) Introduction

For this project, the transportation system in the Niagara Region was considered as an initial approach with the objective of diving into the different bus routes and their schedules to optimize mobility inside the region, however, information for this sector proved quite difficult to acquire. Naturally, looking into Ontario's vast array of cities, the city of Hamilton proved to offer a very thorough database, thus being selected for the project at hand.

The city of Hamilton harbours many beautiful landscapes, including over 100 waterfalls and cataracts. Unfortunately, the transport system for people without cars is not sufficient to provide a means of transport from different entry points of the city to all the interesting destinations the city offers. The City of Hamilton has developed The Transportation Master Plan: City in Motion (TMP), as well as Hamilton's 2024 – 2028 Tourism Strategy, both proposing different approaches to close this gap. To aid in this endeavour, this project proposes a deep analysis of the city's transportation system as well as the reachability of its waterfalls and cataracts, focusing particularly in the most visited and the ones with the best reviews, aiming to connect tourists without cars to these breathtaking destinations.

2) Data Selection and Cleaning

According to the Open Hamilton Data resources, the city has a total of 103 waterfalls and cascades. Of these, 59 were identified as having public access, allowing visitors to explore them. However, based on available online sources such as Tripadvisor and Google Reviews, ratings and visitor feedback were only found for 21 of the publicly accessible waterfalls. Given the limited availability of data for the remaining locations, the analysis will only focus on these 21 waterfalls, as they are the ones that provide the required information regarding visitor experiences, accessibility, and popularity.

Following this selection, two key origin points were selected: Hamilton GO Centre and West Harbour GO Station. These locations were chosen based on the target audience to capture visitors arriving from outside the city. By incorporating these points, the analysis ensures coverage of travelers arriving by train and bus, providing a complete approach to visitor accessibility.

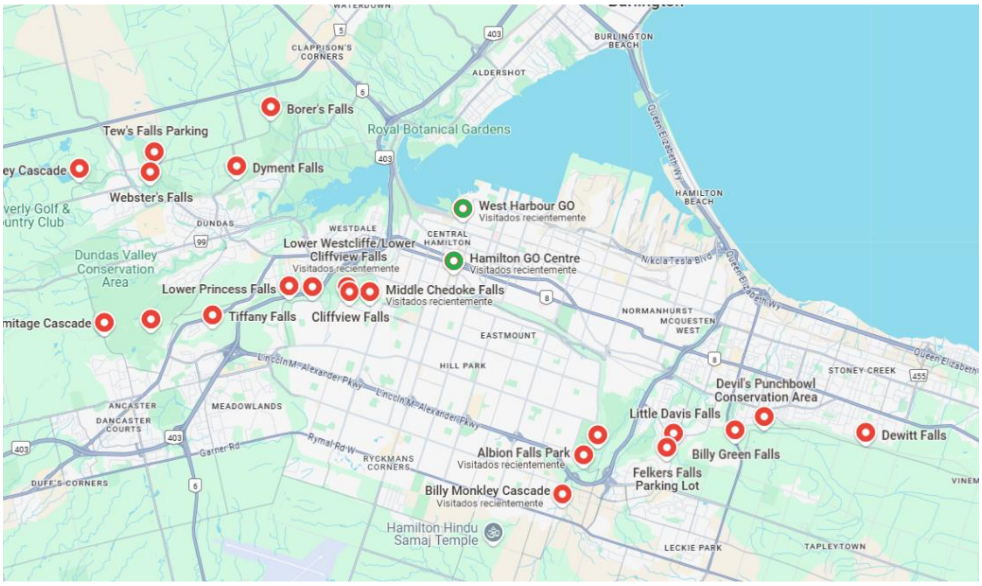

Figure 1: Selected Waterfalls after data cleaning

3) Statistical Analysis

Based on the data collected, it is desired to create several routes according to the location of each waterfall. For this reason, a spatial density-based clustering method called DBDCAN was implemented. This method creates clusters based on the density between points, or in other words, those regions that contain more points according to a specific parameter.

The code was developed using the scikit-learn library with waterfalls' position as latitude and longitude coordinates. The eps parameter was used with a value of 0.03, meaning the maximum distance between two samples for one to be considered as in the neighborhood of the other.

As the objective of the clustering was to use the least number of routes to reach the greatest number of cascades, the following result was obtained.

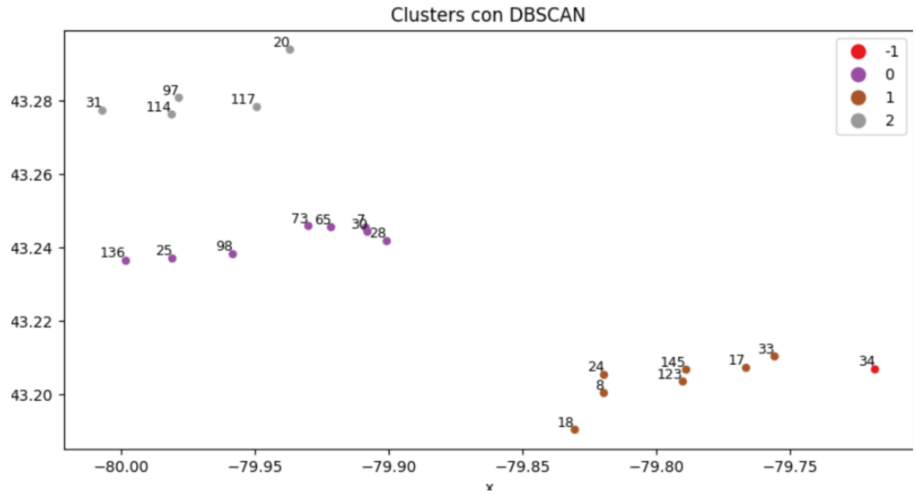

Figure 2. Cluster routes

The “OBJECTID” of each waterfall is presented in the next table.

OBJECTID	NAME	cluster
7	Westcliffe Falls	0
8	Albion Falls	1
17	Billy Green Falls	1
18	Billy Monkley Cascade	1
20	Borer's Falls	2
24	Buttermilk Falls	1
25	Canterbury Falls	0
28	Chedoke Falls	0
30	Cliffview Falls	0
31	Darnley Cascade	2
33	Devil's Punchbowl Falls	1
34	Dewitt Falls	-1
65	Mountview Falls	0
73	Princess Falls	0
97	Tew's Falls	2
98	Tiffany Falls	0
114	Webster's Falls	2
117	Dyment Falls	2
123	Felker's Falls	1
136	Hermitage Cascade	0
145	Little Davis Falls	1

Figure 3. Name and cluster routes

After creating the routes Dewitt’s Falls was removed from the lists due to strategic business decisions based on popularity and accessibility for visitors. This resulted in 3 different paths with five to eight cascades per route. The 3 routes will be presented next:

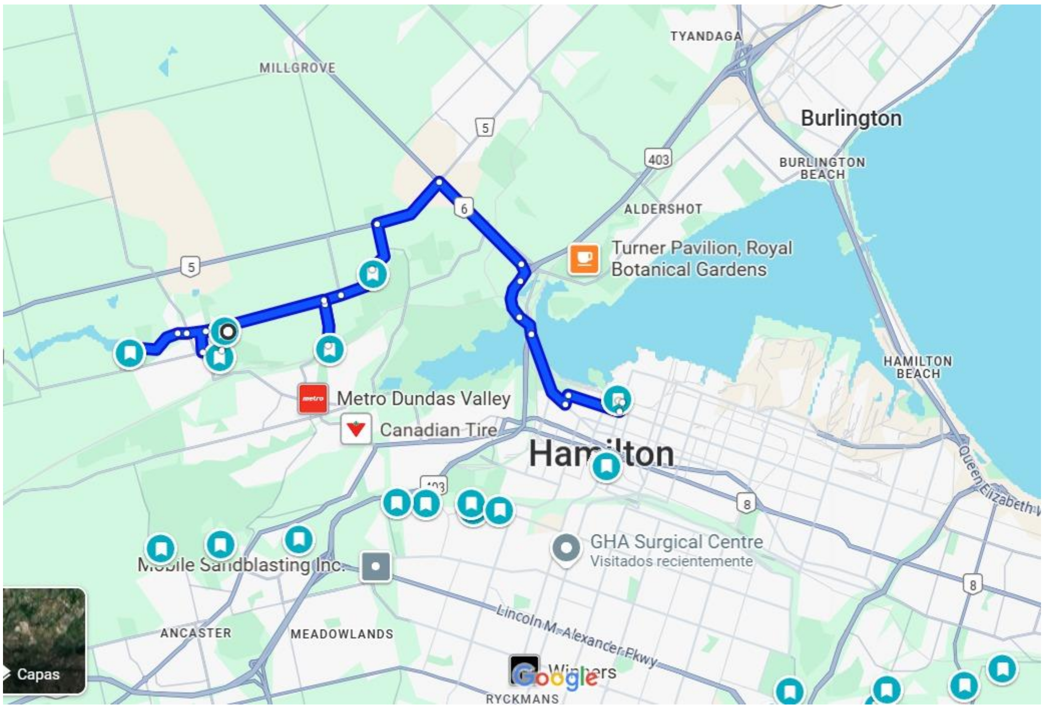

Figure 4: Route 1

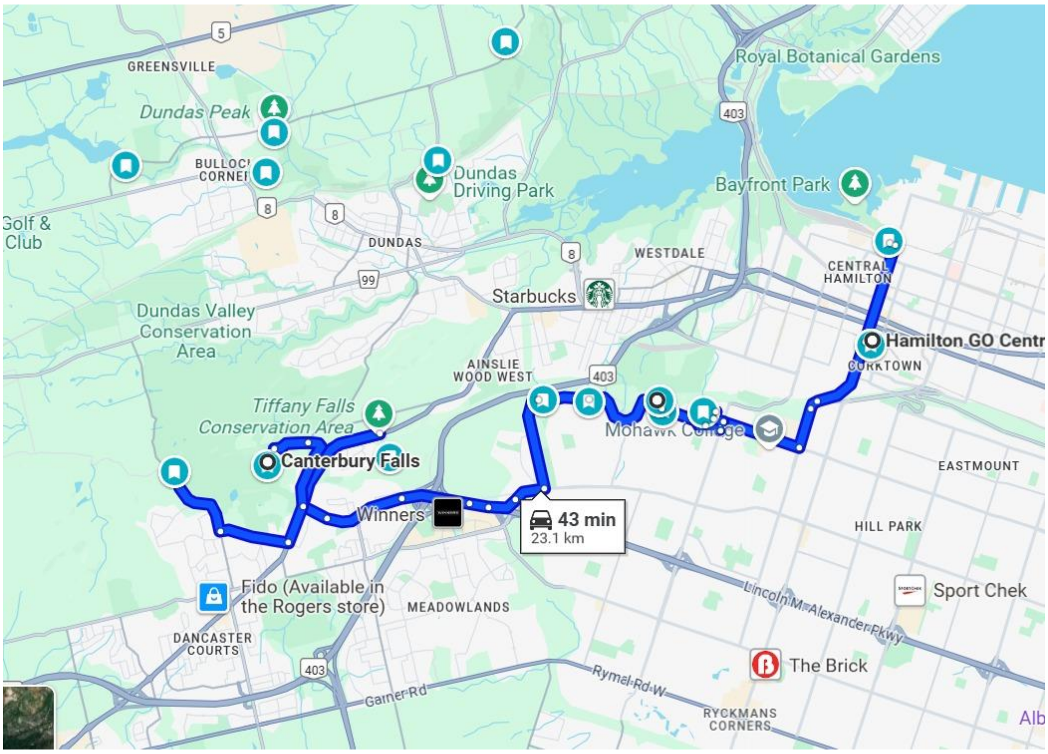

Figure 5: Route 2

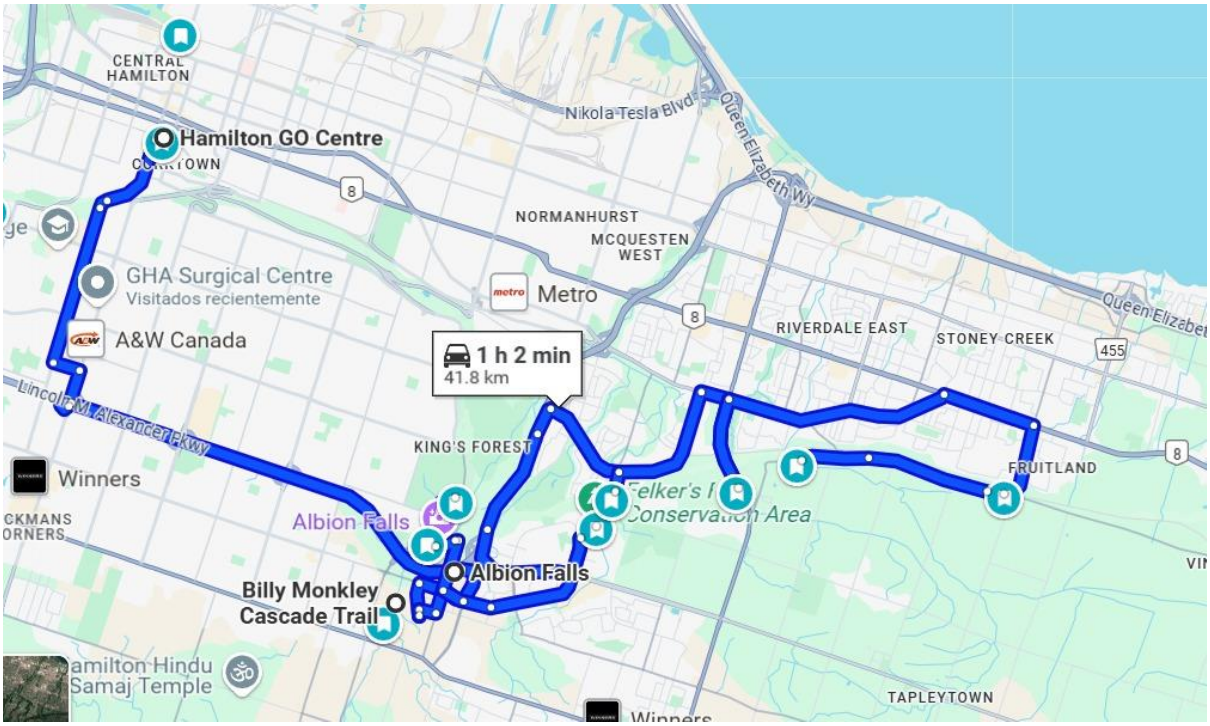

Figure 6: Route 3

Simultaneously an analysis to predict the demand was executed gathering information from Stats Canada and Invest in Hamilton, regarding the average visitors that arrive to the city of Hamilton and distributing them through seasons and taking into account if it's a weekend or a weekday to estimate the fluency of visitors in order to build the mathematical model to optimize the number of buses needed based on requirements established and following restrictions needed

4) Linear programming model development and optimal results

From the previous model, three routes starting at one of the bus hubs and visiting different waterfalls were obtained. The demand was estimated by weighing the seasonal proportion of visitors, estimating the ratio of tourists, and the percentage who would visit Hamilton's Waterfalls.

Each of these values was then segmented into weekday and weekend. With this proportion, a weighted percentage was assigned to each route based on the number of votes and average rating of each waterfall in the route to estimate the tourist distribution per route.

Having predefined the routes and predicted the demand for each season, type of day (weekend or weekday), and route, the mathematical model was created. The model's objective was to minimize the total carbon emissions. For this purpose, two different types of buses were selected, each with a different passenger capacity and a different value of emissions per traveled km as shown in the table below.

Table 1: Bus Specifications

Index (b)	Bus type	size	Passenger capacity	Fuel economy (l/km)	CO_2 emissions (kg CO_2/km)
1	Nova Bus LFS Rigid	40-ft diesel bus	70	0.53	1.4
2	Nova Bus LFS Articulated	60-ft diesel bus	120	0.54	1.54

By mapping each route in Google Maps, the distance and the time required to perform each route was obtained. With this information, the CO2 emissions per route, trip, and bus type were calculated. Based on the amount of time needed to complete each route, a minimum frequency between routes, considering 8 hours operating per day and evenly distributed trips, a maximum of trips per route was defined.

Having all these parameters defined, the mathematical model aims to determine the number of trips needed per route, day, season, and bus type to minimize the total carbon emissions while satisfying the demand and not exceeding the maximum number of trips.

The parameters for the model are as follows:

Table 2: Winter Weekday Demand

Winter Weekday Demand		
Route (i)	Season	Demand
1	Winter	76
2	Winter	249
3	Winter	83

Table 3: Winter Weekend Demand

Winter Weekend Demand		
Route (i)	Season	Demand
1	Winter	163
2	Winter	533
3	Winter	179

Table 4: Spring Weekday Demand

Spring Weekday Demand		
Route (i)	Season	Demand
1	Spring	143
2	Spring	465
3	Spring	156

Table 5: Spring Weekend Demand

Spring Weekend Demand		
Route (i)	Season	Demand
1	Spring	306
2	Spring	998
3	Spring	335

Table 6: Summer Weekday Demand

Summer Weekday Demand		
Route (i)	Season	Demand
1	Summer	353
2	Summer	1151
3	Summer	386

Table 7: Summer Weekend Demand

Summer Weekend Demand		
Route (i)	Season	Demand
1	Summer	756
2	Summer	2467
3	Summer	827

Table 8: Fall Weekday Demand

Fall Weekday Demand		
Route (i)	Season	Demand
1	Fall	156
2	Fall	510
3	Fall	171

Table 9: Fall Weekend Demand

Fall Weekend Demand		
Route (i)	Season	Demand
1	Fall	335
2	Fall	1093
3	Fall	366

Table 10: CO2 emission

Bus Type (b)	CO_2 Emission (kg/km)
1	1.4
2	1.45

Table 11: Route Distance

Route (i)	Route Distance (km)
1	46
2	46
3	82

Table 12: Bus Capacity

Bus Type (b)	Capacity
1	70
2	120

Table 13: Maximum Trips per Route

Route (i)	Max Routes
1	24
2	21
3	13

The model is as follows:

Indices

$$i = 1,2,3, I\text{: } Index\ of\ routes$$

$$j = 1,2, J\text{: } Index\ of\ weekend\ and\ weekday$$

$$k = 1,2,3,4, K\text{: } Index\ of\ seasons$$

$$b = 1,2, B\text{: } Index\ of\ type\ of\ bus$$

Parameters

$$L_i\text{: } Distance\ in\ Km\ of\ route\ i$$

$$Co_b = \ CO^2 emissions\ per\ km\ per\ bus\ b$$

$$D_{ijk} = Demand\ of\ passengers\ in\ the\ route\ i\ on\ day\ j\ on\ season\ k$$

$$K_b = Passengers\ Capacity\ of\ bus\ b1$$

$$MaxRoutes_i = Maximun\ number\ of\ trips\ i\ (frecuency\ every\ 15\ minutes)$$

Decision Variables

$$X_{ijkb} = Number\ of\ trips\ from\ route\ i\ on\ day\ j\ on\ season\ k\ on\ bus\ type\ b$$

Minimize CO2 emissions

$$Minimize\ Z: \sum_{i,j,k,b}^{I,J,K,B} X_{ijkb} * L_i * Co_b$$

Constraints

1. Demand satisfaction

$$\sum_{b}^{B} X_{ijkb} * K_b \geq D_{ijk}\ \forall_{i,j,k}$$

2. Frequency of routes

$$\sum_{b}^{B} X_{ijkb} \leq\ MaxRoutes_i \quad \forall_{ijk}$$

3. Non-Negativity

$$X_{ijkb} \geq 0\ \forall_{ijkb}$$

After running the linear programming mathematical model in PyCharm, the results are presented next.

The annual plan of consumption of CO2 throughout the year is: 350.79 kg of CO2

First the results for weekdays will be presented.

Table 14: Weekday Results

	Bus type 1			**Bus type 2**		
	Route 1	**Route 2**	**Route 3**	**Route 1**	**Route 2**	**Route 3**
Winter	0	2	0	1	1	1
Spring	1	0	1	1	4	1
Summer	0	0	1	3	10	3
Fall	1	1	1	1	4	1

Now the results for weekends

Table 15: Weekend Results

	Bus type 1			Bus type 2		
	Route 1	Route 2	Route 3	Route 1	Route 2	Route 3
Winter	1	1	1	1	4	1
Spring	1	1	0	2	8	3
Summer	1	1	0	6	20	7
Fall	0	2	2	3	8	2

5) Key Insights and Strategic Implications

```
Weekdays:

       | Bus type 1                      | Bus type 2
       | Route 1   | Route 2   | Route 3   | Route 1   | Route 2   | Route 3
Winter | 0.0       | 2.0       | 0.0       | 1.0       | 1.0       | 1.0
Spring | 1.0       | 0.0       | 1.0       | 1.0       | 4.0       | 1.0
Summer | 0.0       | 0.0       | 1.0       | 3.0       | 10.0      | 3.0
Fall   | 1.0       | 1.0       | 1.0       | 1.0       | 4.0       | 1.0

Weekends:

       | Bus type 1                      | Bus type 2
       | Route 1   | Route 2   | Route 3   | Route 1   | Route 2   | Route 3
Winter | 1.0       | 1.0       | 1.0       | 1.0       | 4.0       | 1.0
Spring | 1.0       | 1.0       | 0.0       | 2.0       | 8.0       | 3.0
Summer | 1.0       | 1.0       | 0.0       | 6.0       | 20.0      | 7.0
Fall   | 0.0       | 2.0       | 2.0       | 3.0       | 8.0       | 2.0
```

Figure 7. Output of the LP model

- The selection of Nova Bus LFS Articulate 60ft is more environmentally conscious because even though it hast higher carbon emission per kilometer, it can transport almost double the number of passengers for just 0.05 Kg of CO_2 per kilometre more than Nova Bus LFS Rigid 40ft. Due to this, the model assigns more trips to Nova Bus LFS Articulated 60ft (Bus type 2), especially when demand is higher.
- Nova Bus LFS Rigid 40ft diesel buses (Bus type 1) see most of their usage for trips during fall season, weekdays (3) and weekends (4). This shows that the moderate

demand level allows for the model to approve trips with smaller CO_2 emissions without sacrificing the demand constraint,

- In the fall season weekends and weekdays have the highest usage of Nova Bus LFS Rigid 40ft diesel buses
- Winter Season is the only season that sees routes with only 1 trip per day (route 1 and route 3 during weekdays), every other season sees at least 2 trips per route. If the focus is placed on weekends only. The pattern is similar to weekdays, but the lesser number of trips becomes 2 during Winters. This allows to put less resources during this season and not over-operate a service
- Route 2 gets most of the trips in each season and during weekdays and weekends. This behavior aligns with the estimated demand per route obtained during the data collection phase.
- Nova Bus LFS Rigid 40ft buses are barely used during summer weekdays, just 1 trip per day. This suggests that the model finds a “sweet spot” where it is able to fulfil the demand of the day type for less CO_2 emission per person.

6) Environmental Impact Assessment

The objective function of the linear programming mathematical model was designed to address environmental concerns by minimizing the kilograms of CO_2 emissions produced by buses while meeting demand requirements. This approach aims to reduce the carbon footprint and contribute to the preservation of surrounding ecosystems Additionally; the model incorporates ethical and legal considerations ensuring the safeguarding of the environmental factors to avoid potential legal and ethical risks. By optimizing CO_2 reduction, the mathematical model integrates environmental, legal, and ethical responsibilities.

Political and social factors, that are more challenging to quantify, can be addressed through policies and statutes that promote transparency and integrity in project implementation. These measures would also support sustainable transportation planning in alignment with municipal and federal climate objectives, including Canada's Net-Zero Emissions by 2050 policy.

The project also accounts for economic factors, as lower CO_2 emissions result in optimized fuel consumption, reduced carbon taxes, and minimized environmental penalties. Furthermore, this data can inform potential pricing strategies based on demand behavior, ensuring a balance between cost efficiency and service needs.

From a technological perspective, the project incorporates tools such as Google Maps to estimate route distances and travel times, enhancing data driven planning and operational efficiency. Moreover, it remains adaptable to future advancements, including the integration of electric or hybrid buses, GPS tracking, and AI-based scheduling systems, ensuring long term sustainability and relevance.

7) Recommendations

1. A monthly or weekly continuous evaluation would be recommended, as this is just a pilot model that could be greatly improved by analyzing the demand and obtaining more firsthand reviews from visitors
2. If possible, analyze demographics of visitors to evaluate potential digitalization of the transit platform or change the waterfall’s ratings based on different comparison throughout all social media networks.
3. Having the result of the number of trips for each of the routes, depending on the day and seasonality, it is possible to make pricing strategies, discounts, or family plans to increase the demand on days where the number of routes is low.

4. The input of the model related to the time of the routes was made considering a specific point in time. To give more robustness to the model, different time frames could be implemented according to the hourly peaks of the city of Hamilton, with the objective of having a more realistic value regarding the time each route takes from the beginning to the end.
5. Since this model was created as a pre-planning project, it is important to have as a future steps the maintenance's frequencies of a vehicle, allocation of number of buses to each route in the different days and seasonality, gas and energy prices, and depreciation costs that can be included as a new objective function.

8) References

Goverment of Canada . (2023). *Net-zero emissions by 2050*. Retrieved from Canada.ca: https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html

Hamilton City. (2025). *Datasets*. Retrieved from Open Hamilton: https://open.hamilton.ca/search?collection=Dataset

Hamilton City Hall. (2025). *Hamilton Tourism* . Retrieved from Invest In Hamilton: https://investinhamilton.ca/sectors/tourism

Hamilton Waterfalls Guide. (2025). Retrieved from Tourism Hamilton: https://tourismhamilton.com/hamilton-waterfalls-guide/

SciKit Learn. (2025). *DBSCAN*. Retrieved from SciKit Learn: https://scikit-learn.org/stable/modules/generated/sklearn.cluster.DBSCAN.html

Statistics Canada. (2021). *2021 Census of Population geographic summary: Hamilton [Metropolitan Area], Ontario*. Retrieved from StatsCanada.ca: https://www12.statcan.gc.ca/census-recensement/2021/search-recherche/productresults-resultatsproduits-eng.cfm?LANG=E&GEOCODE=2021S0503537

Statistics Canada. (2025, 05 22). *International travellers entering or returning to Canada, by type of transportation and traveller type, seasonally-adjusted*. Retrieved from Statscanada.ca: https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2410005401

Trading Economics. (2025). *Canada Tourist Arrivals*. Retrieved from TradingEconomics: https://tradingeconomics.com/canada/tourist-arrivals

Trip Advisor. (2025). *Waterfalls in Hamilton*. Retrieved from TripAdvisor: https://www.tripadvisor.ca/Attractions-g154990-Activities-c57-t95-Hamilton_Ontario.html