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An Algorithm for Optimization of Recharging Stops: A Case Study of Electric Vehicle Charging Stations on Canadian's Ontario Highway 401

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Abstract: Electric vehicles (EVs), which have become a fundamental part of the automotive industry, were developed as part of concerted worldwide efforts to reduce dependency on fossil fuels due to their devastating effects on the environment. The aim of this study was to analyse a complete trip using an EV from Toronto to Ottawa (Canada) along Ontario's Highway 401, considering that use of conventional vehicles powered by petrol or diesel allow one to make this trip without stops; using EVs, it is necessary to recharge the vehicle. For this purpose, an algorithm was developed for optimizing recharging stops during a complete trip. In particular, the simulations analysed the number of stops and specifically where it is possible to recharge taking into account the actual charging stations (CSs) located along the trip and the time of recharge during the stops as a function of the state of charge (SoC) of the vehicle. Using this approach, it was possible to evaluate the suitable coverage of the CSs on the stretch considered as well as to assess the main parameters that influence performance on the route.

Keywords: electric vehicles (EVs); charging stations (CSs); highway; type of charging station; optimization

1. Introduction

A network of highways has become a common feature in modern cities. Throughout the day, these highways facilitate the transportation of people and goods that enable the sustenance of lifestyles. When thinking of the word "road" today, it is common to have a mental picture of busy, congested lines of traffic and long commutes [1–3]. Perhaps one also thinks of potholes and falling shoulders. If one lives in a location that has well-maintained or little-used roads, perhaps one thinks of a peaceful two-lane road winding through the trees between distant cities [4]. For many people, roads are a resource reluctantly used nearly daily to move from a position A to a position B. Highways are generally composed of two roads with two lanes going in opposite directions [5]. Conferring to European Union law, highways and main roads have to be endangered by a safety screen barrier located on both faces of the two lines to prevent infiltrations into the asphalt. It is also widespread to get instructive boards providing weather updates and information about the state of roads, accidents, and traffic conditions.

The intense collective mandate for enhanced security, accessibility, transportation effectiveness, and environmental sustainability leads to continuous innovations in vehicular technology whilst being mindful of the need for sustainable energy use for future generations. In the automotive industry, compelling challenges in automotive technology are improvements in safety, efficiency, and convenience and reduction in harmful environmental impacts [6–8]. Modern transportation systems are confronted by many limitations, especially the inconvenience of safety gadgets, environmental impact of emissions, and congestion. Happily, these are solvable with determined efforts and strategic implementations of technological innovations. These technological innovations that support secure and accessible transportability centred on improved propelling environments have been built by utilizing vehicular transmission [9,10]. The equipment for communication coupled with vehicles that have the capacity to connect to this equipment has to be a fact for effective and secure utilization of forthcoming road. Exploiting automotive connectivity and automatic vehicle technologies to produce an intelligent vehicular system with consideration for security, outputs, and necessary accessibilities requires one to connect a central task of intelligent transportation system (ITS) judicious scheduling and execution [11].

ITS refers to the use of sensing, analysis, control, and communication technologies to a vehicular system for the purpose of enhancing protection, traffic, and efficacy. ITS comprises a comprehensive variety of tools that analyse and communicate data to simplicity jamming, develop circulation controlling, reduce negative ecological impacts, and improve the advantages of transport services to business operators and the community all together [12,13]. ITS is a component of the Internet of Things and includes vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) technologies. It combines both wireless and wired communication-based data and electronic equipment. Wireless technology can be deployed to link a vehicle to other vehicles (to share information and location) and to local and remote infrastructure in the cloud [14]. ITS has the ability to profoundly influence many applications. Some of these include: electronic fee collect, ridge meters, transit-signal synchronization, traffic-signal priority, traffic-light cameras, and information systems for travellers. The implementation of ITS is anticipated to rise in functions such as tolling management, fleet monitoring, transportation pricing, ticket controlling, and traffic flow monitoring [15–17]. Travellers, businesses, and transportation agencies will benefit from the ITS safety improvements as well as the availability of real-time data and analytics [18,19]. The establishment of information technologies in actual-time monitoring of highways will allow a reduction in maintenance costs and is anticipated to significantly decrease circulation accidents. There are other difficulties occasioned in assessing new applications and implementing the technology within vehicle fleets and regions when possible. For example, if temperature along a highway can be determined, that information could assist in preventing asphalt from freezing, since salt could be spread where and when it is needed. With that information, costs can be lowered by decreasing the quantity of salt to be distributed and preserving the asphalt, as this is corroded by salt [20–22]. Furthermore, safety can be improved by lowering the speed maximum based on the condition of the asphalt through alive information displayed in informational boards. Another example is the wire fence. For safety motives, it is essential to maintain wired barrier in a satisfactory condition. If, for instance, the barrier collapses and a wild animal enters the road, it could cause a crash. In conformity with the laws in some European Member States, it is required to verify the safety wire barrier at a minimum once each day. If that security fence can be monitored in an automated and real-time manner, security would be enhanced, and there would simultaneously be reduced maintenance costs [23,24].

Technological improvements to transportation and mobility are affecting the designs and the build of vehicles by manufacturing companies. Electric vehicles give bigger incentive for lower energy financing at lower emission intensities. EVs emit fewer greenhouse gases that affect the climate than nearly all comparable gasoline and hybrid cars [25,26]. The environmental benefits of EVs continue to grow. Innovative and weightless materials help vehicle manufacturers to decrease overall vehicle mass without jeopardizing traveller security. It is estimated that, by 2022, there will be over 250 million connected vehicles [27,28]. This turns in huge data collection by a car's sensor sets on wheels that can be exploited for future development and to generate cutting-edge comprehensive models on many factors, for instance, circulation stream or precise route maps. Envision a map displaying all the deep holes on the street and the capability to evaluate each hole live, such that the highway groundwork would be rapidly repaired. Imagine that all cars are connected and have integrated communication technology to offer helpful aids to car users. Vehicles equipped with electronic control components and sensors that support V2V and V2I communications can effectively recommend re-directing to escape path dangers as well as request for help in the occurrence of an accident. In the last few years, a novel mobility concept emerged as a paradigm of personal mobility consumption founded on pay-per-use and is diffused among the younger generation. Surely, there could not be a smart city without smart mobility, and no smart mobility is conceivable excluding smart roads.

As indicated in the literature, numerous feasibility, simulation, and optimization studies were accomplished on EV charging stations powered by energy sources, including renewable energy sources as well [29–43]. The interpretation drawn is that it appears that no algorithm for optimization of recharging stops or other similar work has been performed on such EVs on Canadian's Ontario Highway 401; thus, the current investigation is an original research proposal and a certain contribution to knowledge.

As mentioned earlier, this study aims to develop an algorithm that would optimize recharging stops during a complete trip from Toronto to Ottawa (Canada) along Ontario's Highway 401. Through the analysis of simulation data, this paper examines the difference in time between selected electric vehicles and standard petrol/diesel vehicles; the latter are in most cases able to complete the trip with a complete fuel tank.

The rest of the article is organised along these lines: Section 2 gives thoroughly various typology of charging stations taking into account the diverse recharging methods. Section 3 defines the case study, whereas Section 4 provides the algorithm's design incorporating the modelling technique and a detailed description of the method. In Section 5, features of the simulation outcomes are presented and supported by their analyses. Lastly, Section 6 provides the key conclusions obtained in this work.

2. EV Charging Stations

The transportation sector currently relies on liquid fossil fuels originated from petroleum oil for 95% of the total fleet, which suggests that 50% of the petroleum oil production is consumed simply for transportation. Electric or hybrid vehicles present a viable and attractive solution to the many problems caused by dependency on liquid fossil fuels [44,45]. Importantly, the energy storage systems of electric and plug-in hybrid vehicles and their connection to renewable energy sources via recharging stations are a significant benefit for the central grid [46]. As mentioned in the previous section, EV charging stations located along the highway in an even distribution are a fundamental feature of a smart highway [47–49]. An outline of diverse sorts of charging stations and different charging modes is discussed below.

2.1. Types of Charging Stations

Charging stations are constructed by numerous companies in a range of arrangements and may be either installed on poles, built on walls, portable, or in columns. They can too include diverse approval selections. Presently, the predominant routine way to open the socket of the charging station and start charging the vehicle is the radio-frequency identification card. According to the appropriate area of use, the charging columns require one to satisfy several specifications. They may commonly be distributed into two principal types:

- Private charging stations: These are commonly used in the private sector. Depending on the situations, these could or could not be available to the community. They are often used in family homes, shops, hotels, car dealerships with repair shops, shopping malls, restaurants, banks/insurance companies, and company car parks.
- Public charging stations: These are often mounted on public infrastructures or in public car parking lots situated in railway stations, aerodromes, or further unrestricted spaces. There is need to clarify the distinction between charging stations and charging points. Certain charging stations are supplied with two or more cables or connectors and have the capability to load two or additional vehicles simultaneously. Each connector is usually represented as a charging point, and this expression is usually employed when relating charging accessibility. Otherwise stated, a

station with a single cord is considered as one charging point, and a station with two cords and the capacity to charge two vehicles at one period is regarded as two charging points. This assists to evaluate the accessibility of charging points further precisely than totalling the stations themselves.

EV charging machines consist principally of electronic components, which can be either on or off board. They supply electricity for the vehicle storage system along with the present equipment for power supply. Generally, home chargers and public chargers (excluding fast-charging stations) provide AC current, but an electric-vehicle battery can only accept direct current (DC) current. Therefore, the on-board charger, which converts AC to DC to charge the battery, is required. Standard on-board chargers decrease the charging power due to their weight, size, and price restrictions (modern on-board chargers have a max power output ranging between 3 and 22 kW), and they are commonly employed to charge battery banks that require an extended charging time.

2.2. Charging Methods

The charging apparatus for plug-in hybrid electric vehicle (PHEV) and battery electric vehicles (BEV) are categorised by the rate at which the batteries are charged. The duration of the charging mode (usually ranging between 15 min and 10 h) depends on the capacity of the battery that is installed on-board, the type of the electric vehicle supply equipment (EVSE), and the initial state of charge (SoC). The European Standard IEC 62196 establishes four diverse charging types in accordance with different power-charging levels, safeguard systems, and connector types [50,51]. The four charging modes are briefly described below:

- Mode 1: In Mode 1 charging, the EV is connected to an alternating current (AC) supply network by means of a non-specialised domestic plug. The limit current does not surpass 16 A, and the limit voltage does not exceed 250 V for a single-phase AC network or 480 V for a three-phase AC network. Mode 1 necessitates both an over-current safety device and shielding earth conductors. A circuit breaker (CB) is used for over-current protection, and a ground fault interrupter (GFI) for switching off the circuit at any time the electric current is unbalanced within the energized conductor and the return neutral conductor. The use of a surge limiter is advised. IEC 61851-1 does not demand the use of any control pins for Mode 1 connectors. However, Mode 1 charging is not allowed in several nations, including the US.
- Mode 2: The connection of an EV to an AC supply network is described as Mode 2 charging. In this case, the limit current does not surpass 32 A, and the limit voltage is lower than 250 V for single-phase or less than 480 V for three-phase networks. Mode 2 charging needs over-current safety, a shielding earth, and a residual current protective mechanism for isolation from electric shocks. A charging control system is combined by means of an aligned unit in the charging cable. Therefore, Mode 2 couplers involve a control pin (defined in IEC 61851-1) on the vehicle side. However, the network side of the cable does not necessitate a control pin, as the control module is embedded in the charging cable.
- Mode 3: With Mode 3 charging, the EV is connected to a charging equipment, which is always hooked up to either a single-phase or a three-phase AC network. The functioning of the charging control pilot is controlled by the on-board charger in the EV as well as the electric vehicle supply equipment (EVSE) control package in the off-board installation. Mode 3 charging needs surge current protection and a ground fault interrupter inside the charging station. A surge arrester is recommended to insulate components from high DV/DT voltage surges. IEC 61851-1 requires the implementation of several controls and signal pins in the coupler. A pilot pin in the plug on the side of the charging station regulates the circuit breaker, which switches off the charging station when no vehicle is connected.
- Mode 4: In charging Mode 4, the EV is connected to a single-phase or a three-phase AC grid with an AC/DC converter. An external EV charger is deployed to allow fast charging. Mode 4 DC fast charging tolerates currents not exceeding 400 A. The vehicle is hooked up with an IEC

62196 standardized connector on the vehicle side (every mode allowed) and with an IEC 62196 Mode 3 connector on the side of the charging station. Mode 4 charging stations must integrate AC/DC-sensitive GFIs and distinct surge protection instruments for AC and DC. The control and the signal pins of a Mode 4 connector are analogous to those of Mode 3 connectors in conformity to IEC 61851-1.

3. Case Study: From Toronto to Ottawa (Canada) through ON-401

King's Highway 401 is currently the main across itinerary through Southern, Central, and Eastern Ontario from Windsor to the Quebec border (stretching across 817.9 km). Millions of travellers use the highway. In particular, nearly half a million vehicles pass through the busiest part of the route (Toronto bypass, shown in Figure 1 below) daily, along sixteen lanes of traffic. It is also utilised by thousands of transport trucks daily, which carry merchandise to and from Ontario producers and customers [52]. The economic motion facilitated by Highway 401 is immense. This highway has been instrumental to Ontario's wealth over many years. There exist 19 Service Centres located along Highway 401. These centres are open around the clock and recommend drivers accessible entrance to services including refuelling, eating places, and rest stops. The displayed speed limit on Highway 401 is 100 km/h (60 mph).

Figure 1. Greater Toronto Area collector-express lane configuration.

As stated earlier, the aim of this paper was to analyse the difference in time between an internal combustion engine (ICE) vehicle and an EV during a complete trip from Toronto to Ottawa. Figure 2 indicates that the total distance from Toronto to Ottawa is approximately 435 km. The first part of this route involves ON 401 from the Greater Toronto Area (GTA) up to the Prescott area, then 416 Highway leads to Ottawa. A quasi-ideal condition was employed as a model development and for analysis of final results. As illustration, for traffic information, it used the "Typical Traffic" function of Google Maps. Ultimately, Google applies a mining process on collected data and runs prediction algorithm to provide "Typical Traffic". To estimate the total travel time from Toronto to Ottawa for a normal vehicle, a midweek morning (Wednesday) starting at 09:00 was chosen. The total time for a complete trip is about 4 h and 20 min. Taking into account a normal-sized petrol/diesel vehicle, it can complete the trip without stops or at least with only one brief refuelling stop lasting for a few minutes.

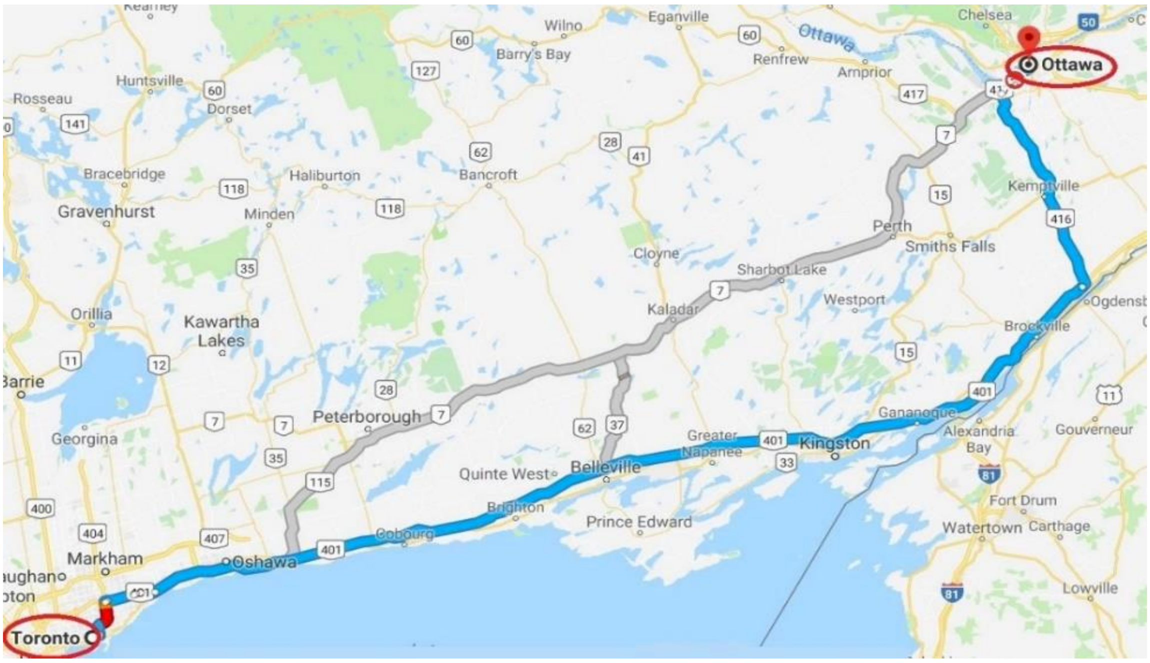


Figure 2. Itinerary Toronto-Ottawa.

3.1. EV Charging Stations

This section analyses the current state of EV charging stations en route between Toronto and Ottawa. While gas stations can commonly be found along the way, commercial electric vehicle charging stations are still fewer in number and less than the demand for them. Luckily, getting from one end of Highway 401 to another is easier for owners of electric cars because of the availability of several stations. As shown in Figure 3, along the route from Toronto to Ottawa, there are many Level 2 charging stations. Level 2 charging (240 V AC) can be placed within the inexpensive Level 1 and costly DC fast charging stations. Level 2 chargers span from chargers set up in end-user garages to fairly slow public chargers [53,54].

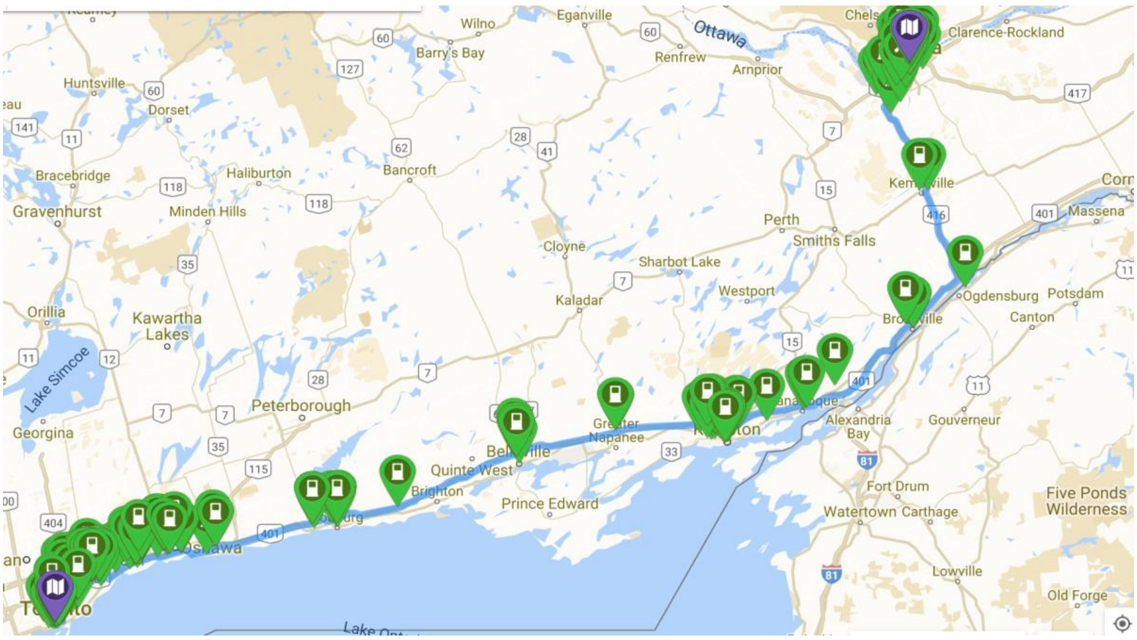
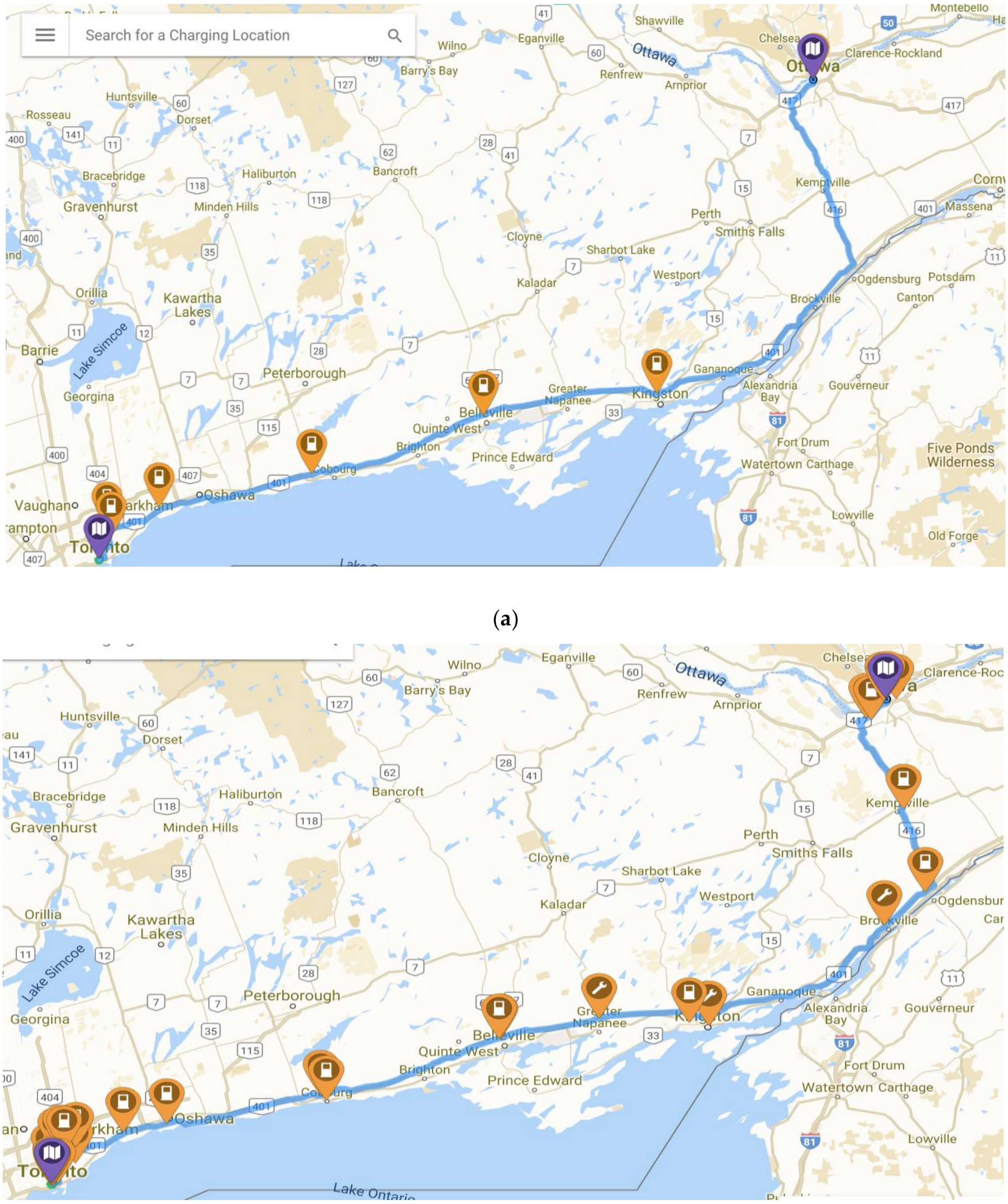


Figure 3. Level 2 charging stations.

Unfortunately, they are able to charge an electric car battery in about 4–6 h. Despite the numerous Level 2 charging stations, from now on, we considered only DC charging stations. The reasoning is easy to follow looking at charging time (4–6 h exceeds the total time needed for a complete trip). Figure 4 shows, respectively, the Tesla Supercharger and the CHAdeMO charging stations. A great difference in numerical terms can be seen between Level 2 chargers and DC fast chargers. This is because there is a peripheral charger that makes the AC/DC conversion much larger, weightier, further complicated, and more costly than an on-board charger.



(**a**)

(**b**)

Figure 4. (**a**) Tesla Supercharger; (**b**) CHAdeMO charging stations.

3.2. EV Comparison

Recall that the aim of this paper was a comparison between EV and ICE vehicles during a travel from Toronto to Ottawa. To further enable this discussion, the vehicle's characteristics were studied. For the model construction, official ratings were required. The kilometre ranges of selected vehicles were calculated using Environmental Protection Agency (EPA) energy consumption related to a highways use. The U.S. Environmental Protection Agency is the governmental agency responsible for testing electric cars and rating their energy efficiency and, specifically, their operating range on a charge. Those ratings are not infallible, but when compared to other ratings around the world, they are easily achievable and more accurate. These are not exactly correct and vary depending on multiple factors. It is well known that EV efficiency is dependent on several elements, including battery, SOC, kW of charging station (CS), and charging time. It is similar to the fuel gauge in conventional internal combustion cars. In order to advance to more practical aspects, five BEVs were selected from among best-selling EVs of Ontario in Q3 of 2018. It is noted that highway cycle range is expressed in miles per gallon gasoline equivalent (MPGe). MPGe is a measure of the average distance travelled per unit of energy consumed. MPGe is employed by the United States EPA to evaluate energy consumption of electric vehicles with the energy consumption of conventional internal combustion vehicles rated in miles per US gallon [55,56]. In particular:

$$1\ MPGe \approx 0.03 \frac{mi}{kWh} \approx 0.05\ \frac{km}{kWh} \quad (1)$$

From this value, the highway kilometre range of all five cars can be calculated.

Table 1 summarises the main selected vehicles, which are those of 2018 model cars. The major characteristics are: battery capacity, range (km), charging time, and MPGe.

Table 1. Selected vehicle's main data.

Model of EVs		Battery Capacity (kWh)	EPA Range (MPGe)	Range (km)	Charging Time (min)
Kia Soul		30	93	133.36	44:00
Nissan Leaf		62	97	287.54	60:00
Tesla Model 3		75	112	401	57:00
BMW i3		42.5	102	205.5	60:00
Tesla Model S		100	107	487.6	65:00

EPA: Environmental Protection Agency; EV: electric vehicle.

4. Optimization Algorithm

This section reviews the realised JavaScript tool. It is conventionally employed to simplify analyses in a case study. As written in the previous section, this analysis was performed by reference to ideal conditions. Note that the energy consumption of EVs was variable and dependent on a number of external factors such as road topology, traffic density, driving style, and ambient temperature. The parameters related to EV energy consumption and charging time were taken from different EV testing societies, thus they could differ a little from the real one. In particular, the EPA highway range was factored into calculations.

The assumption was that all charging stations are always available. First, variables and formulas worked into the algorithm are defined below. For the sake of simplicity, all the EV charging stations were considered available at the moment of need.

Before examining the algorithm's specifications, the following assumptions were made: (a) availability of EV charging station; (b) constant charging time; (c) ideal EPA range; (d) vehicles are charged up to 80% at each stop; (e) SoC percentage is consistently maintained at over 20%; (f) vehicles arrive at Ottawa with 30% SoC remaining; (g) if SoC is under 30%, warning message is displayed; (h) only DC fast charge is considered; (i) experiment is at standard temperature; (j) 120 kW Supercharger; (k) 50 kW CHAdeMO.

4.1. EV Variables and Parameters

First, all variables of the optimization algorithm were introduced. Some of them required calculations and a specific coding.

- SoC: It is an input value. It indicates the percentage point of the battery pack of EV (0% = empty; 100% = full). The starting SoC must be greater than 20%, otherwise errors will occur, and a warning is displayed.
- Range: It is the total kilometres that the vehicles can travel. The values considered in the equations are reported in Table 1.
- Charging Time (Ct): It is a manufacturer's data (an ideal value and not a real one). It differs for each EV considered.
- Actual Starting point (dc): It is value that is updated whenever a car arrives at a new charging point.
- Maximum allowed distance (x): It is a simple sum of current range and actual starting point.
- Current Range ($A1$): It is calculated starting from two input data, SoC and car's ideal range (manufacturer data). It represents the maximum range (in km) allowed up to 20% of SoC:

$$A1 = \frac{(SoC - 20)}{100} \cdot range \tag{2}$$

- Remaining Charge (CR): It represents the percentage of charge remaining when the vehicle arrives at the charging station:

$$CR = \left(\frac{(x - dc)}{range} \cdot 100 \right) + 20 \tag{3}$$

- Current Charging Time (CCT): Time spent to recharge vehicle at stop number n:

$$CCT = \left(\frac{(SOC - CR)}{60} \cdot Ct \right) \tag{4}$$

- Final Charge (FC): Percentage of charging at final point (arrive):

$$FC = \left(\frac{(A1 - d)}{range} \cdot 100 \right) + 20 \tag{5}$$

4.2. EV Comparison

The algorithm received the following as input data: departure point, arrival point, type of EV, and percentage of starting SoC. Depending on EV and level of SoC selected, the range and the ideal charging time were automatically derived. Figure 5 represents the algorithm used in the work. First of all, the level of SoC was considered. If it was below 20%, an alert message appeared. If the starting

SoC was more than 20%, distance and current range were calculated. While the current range was lower than the distance, an EV had to be recharged in one of the charging stations located at a point before the maximum allowed range. This cycle ended when a final point was reached. The algorithm ensured that EVs arrived at their destination point with 30% of SoC as quickly as possible. It gave an alert if the percentage of SoC at final destination was less than 30%. Ultimately, software output showed a list of recommended stops. As said in the previous section only, DC fast chargers were taken into account due to the extensive time required for charging Level 2 chargers. At each stop, the following information was displayed: address, charging time, and percentage of battery recharged. Total number of stops and total charging time were also displayed.

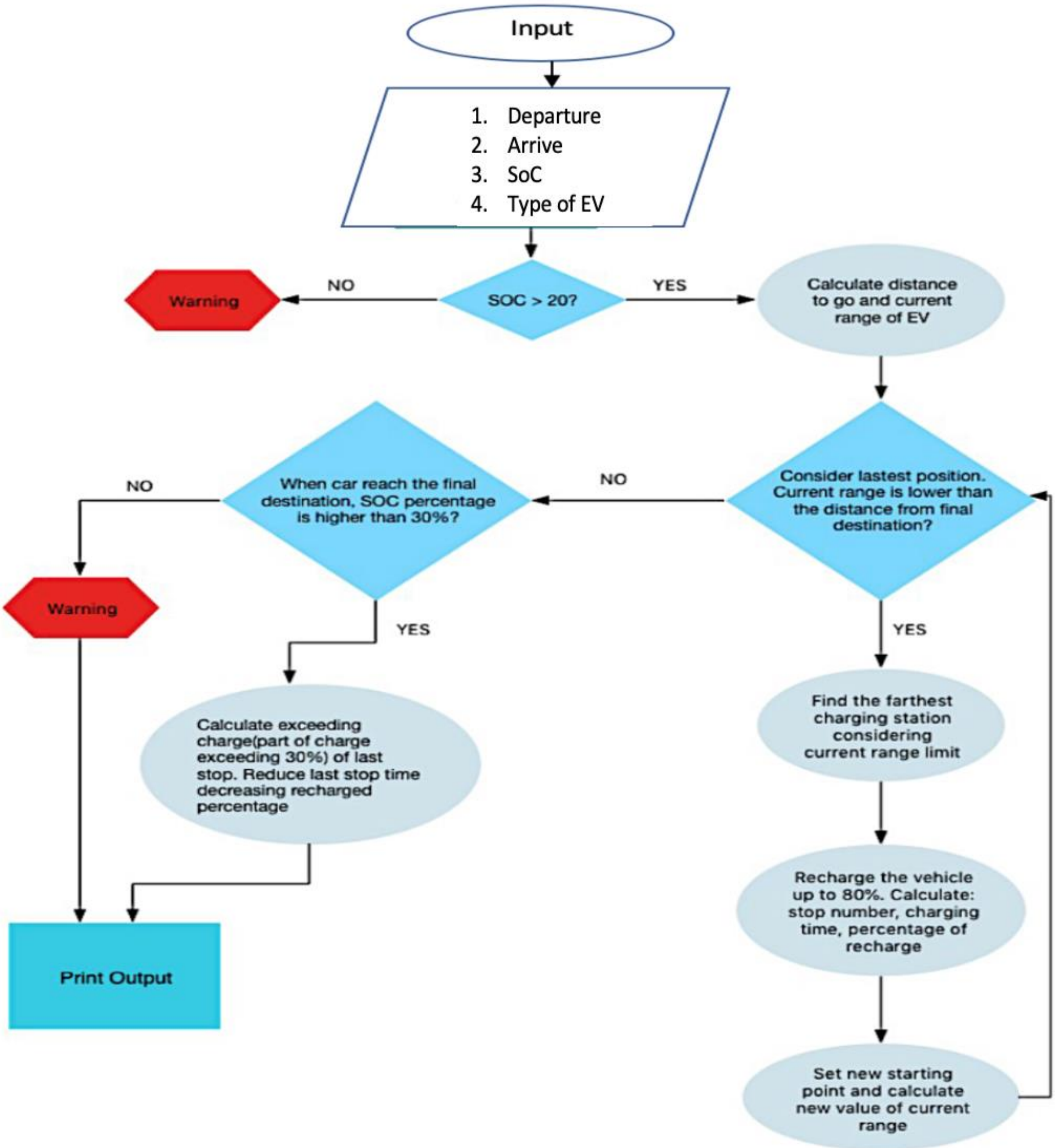
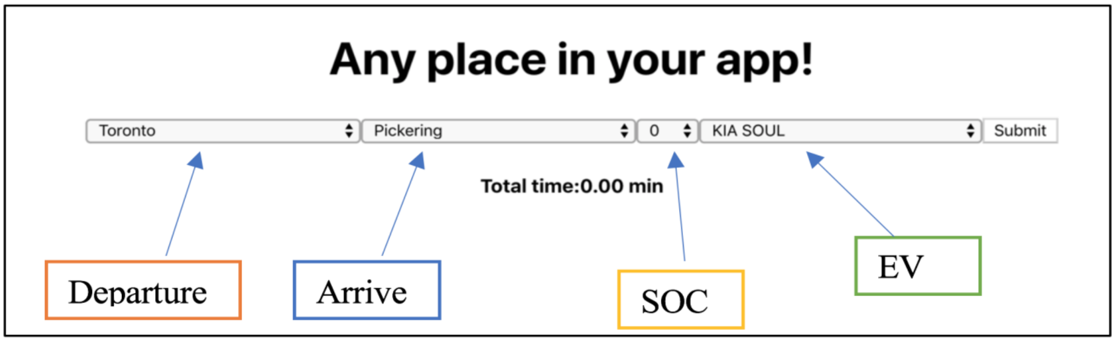


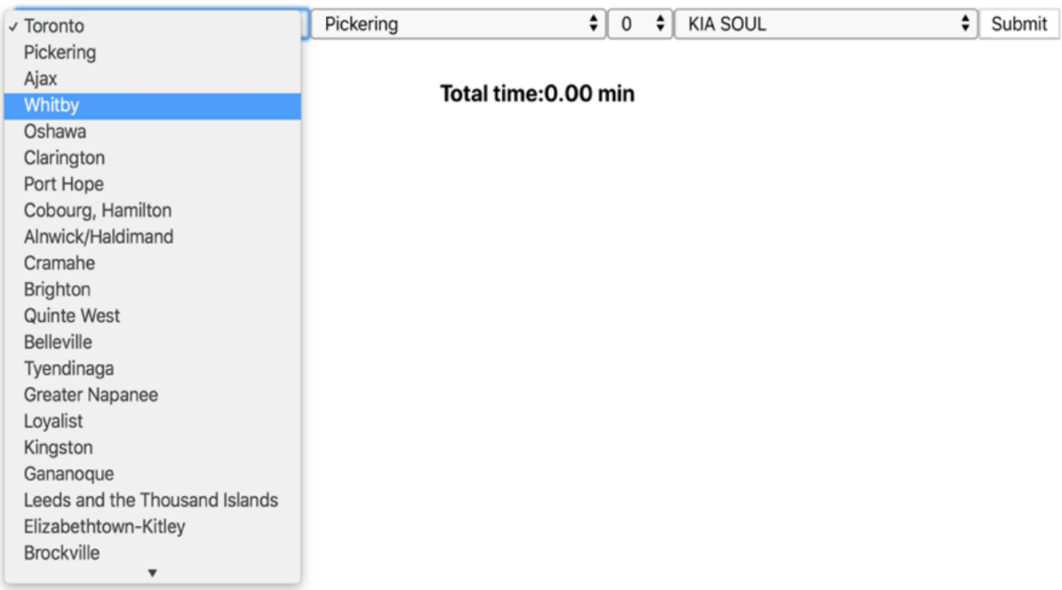
Figure 5. Developed algorithm overview.

As shown in Figure 6a, a user may insert input values using the drag and drop menu. It shows detailed visualization of the four input values—origin, destination, type of vehicle used in the trip, and state of charge. The user can choose a starting point from a list of cities situated between Toronto and Ottawa (Figure 6b). Arrival and destination times must be chosen after the starting point along the way, otherwise a warning will be displayed. One of four EVs can be selected (Figure 6e). Finally, the user can indicate starting SoC percentage (Figure 6d). Users can select departure/arrival input values from the following list of cities situated between of Toronto and Ottawa along Ontario-401 Highway (Figure 6b,c).

After all the input parameters are selected and submitted, the algorithm produces an output. Output is divided into two parts. The first part is characterised by recommended stops. The second part is the sum of total number of stops and total charging time.

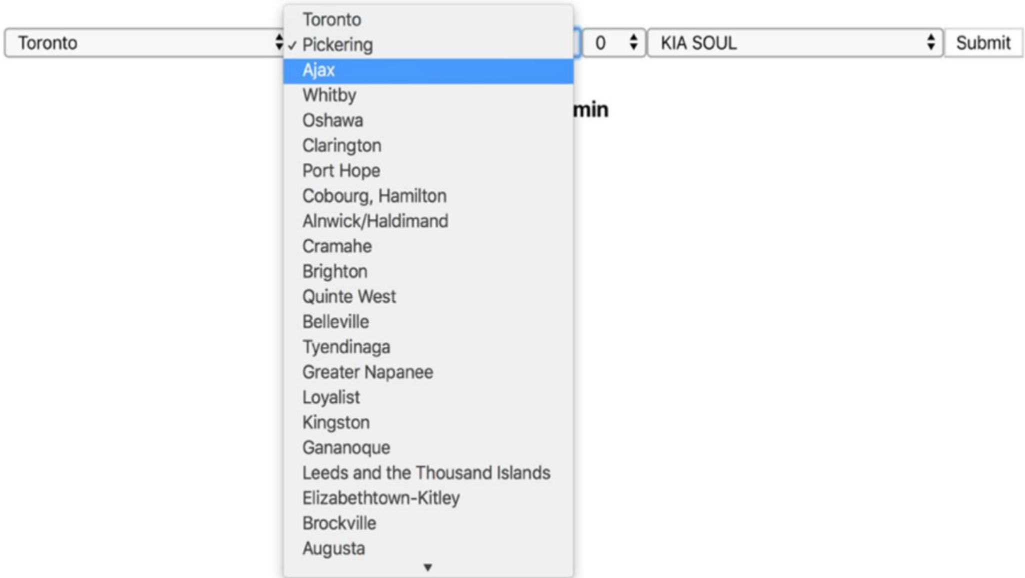


(**a**)



(**b**)

Figure 6. *Cont.*



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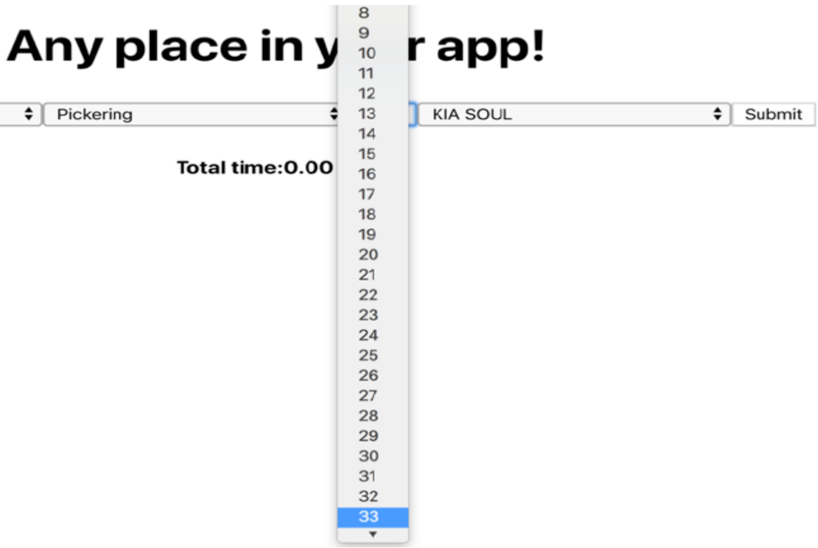


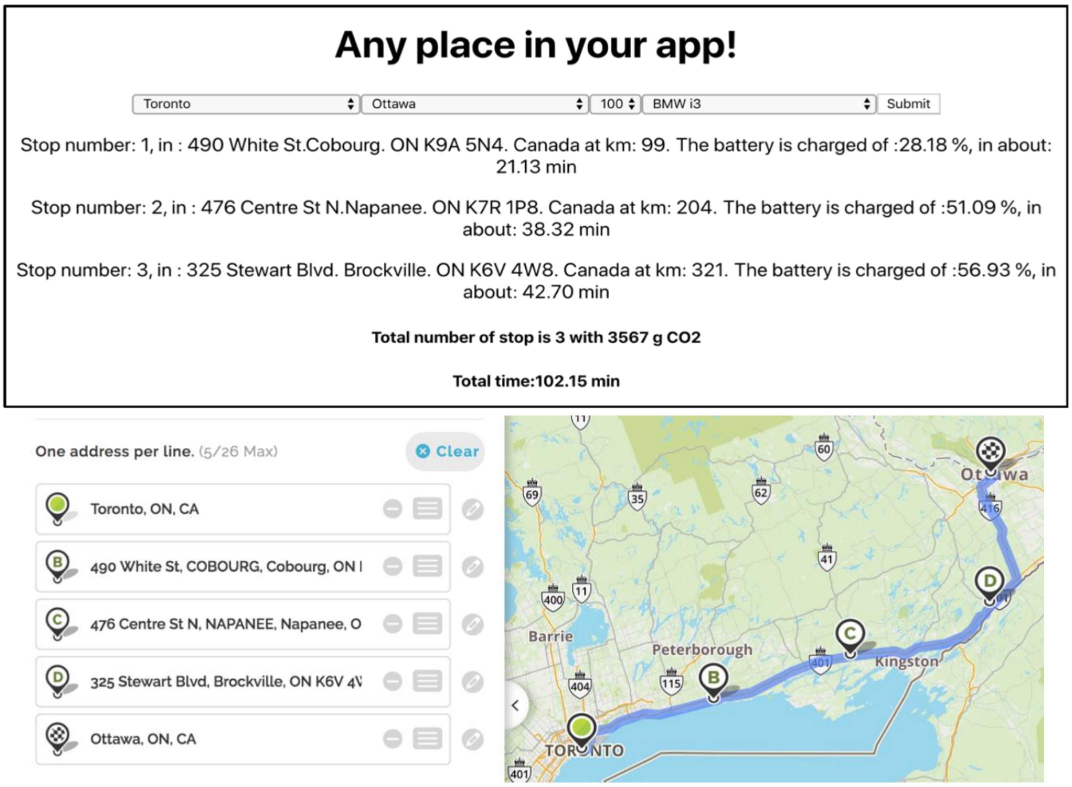
(**d**)

(**e**)

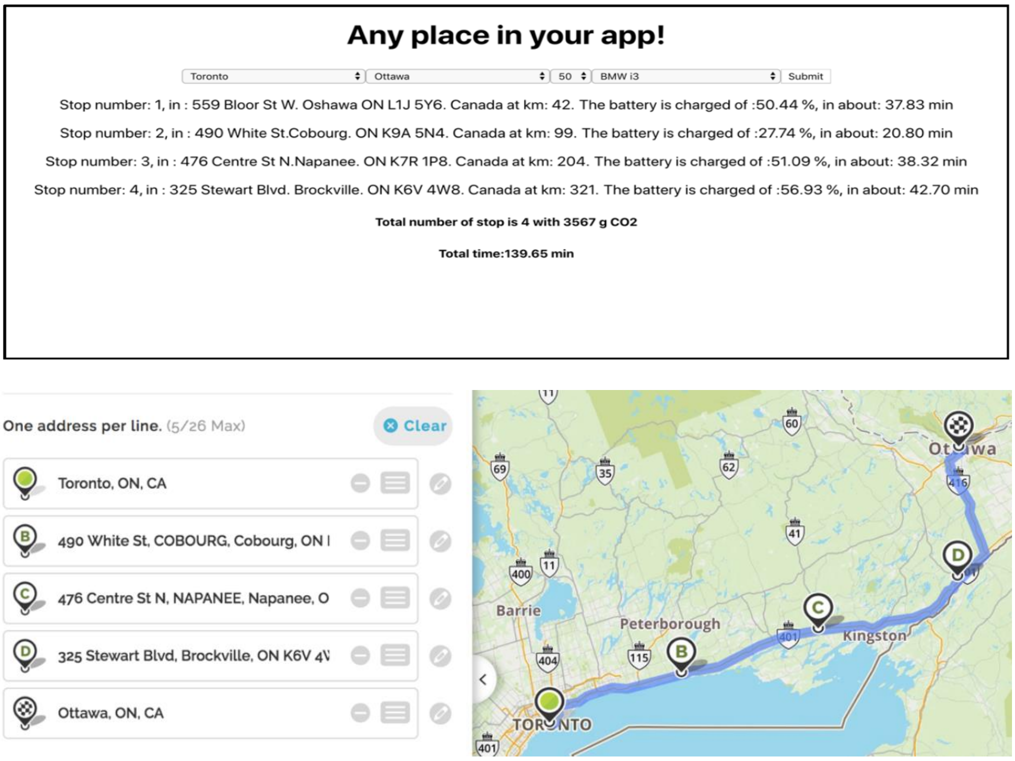
Figure 6. App interface: (**a**) general description and details, in particular (**b**) departure–origin, (**c**) arrival–destination, (**d**) state of charge of the vehicle, and (**e**) type of electric vehicle using in the trip.

5. Results and Discussion

For all the selected EVs, two tests were carried out; the first one was with a 100% initial SoC, and the second one was with an initial SoC equal to 50%. At the end of simulations, Javascript tool returned the total number of stops, the addresses of stops, and the total charging time during a complete trip from Toronto to Ottawa. Figure 7 shows the results obtained for the algorithm taking into account different states of charge and considering as a type of electric vehicle the BMWi. In particular, there were different situations reported considering a differrent state of charge of the vehicle in the departure, for example, when SOC was equal to 100% (Figure 7a) and SOC was equal to 50% (Figure 7b).



(a)



(b)

Figure 7. BMW i3: (**a**) 100%; (**b**) 50% initial state of charge (SoC) test.

5.1. 100% Initial SoC Tests

Assuming that a car starts with a fully charged SoC, both Tesla cars can complete a full trip from Toronto to Ottawa, each with only one stop lasting for 35 min and 20 min, respectively. The case is different with a Nissan Leaf E+ vehicle. It needs two stops, with the first one happening after 204 km and the second one after 341 km from Toronto, and a total charging time of more than one hour. The BMW i3 requires three stops to get Ottawa. Considerably worse are the results of Kia Soul. It needs at least five stops with a total charging time of two and a half hours. Figure 8 represents the number of stops as a function of kilometres travelled considering different types of vehicles with 100% SoC.

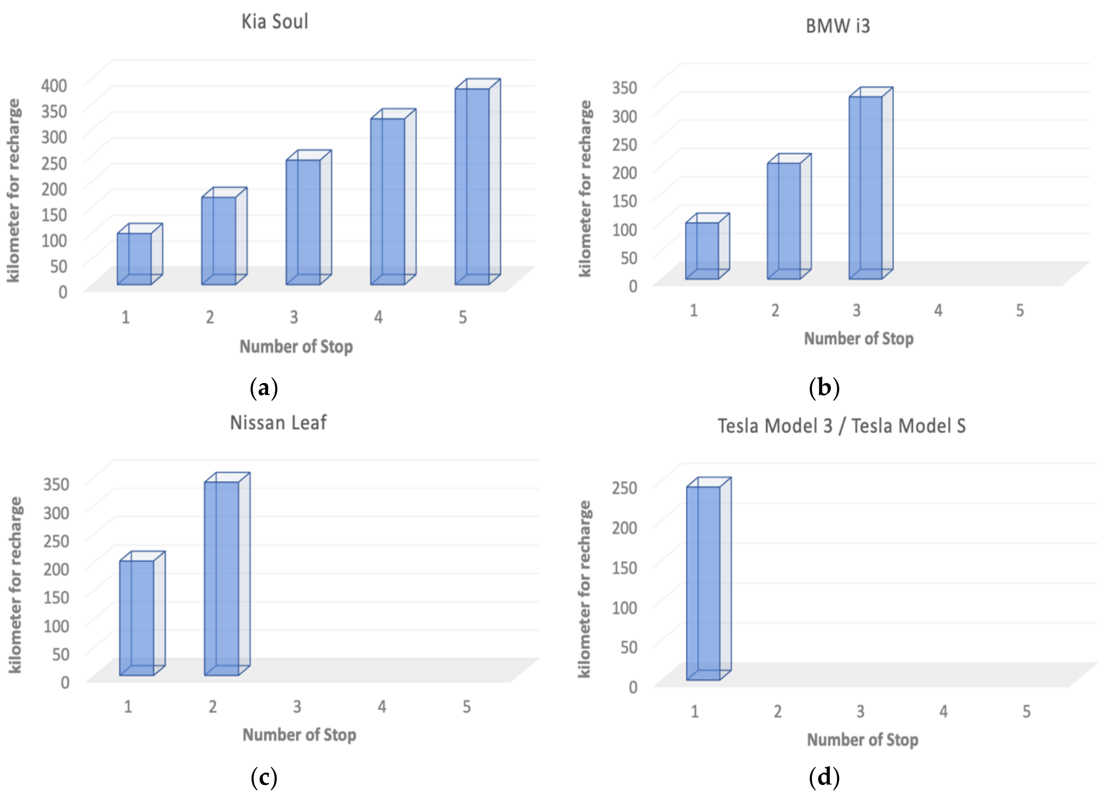


Figure 8. Number of stops as a function of kilometres travelled for different types of vehicles with 100% SoC: (**a**) Kia Soul; (**b**) BMWi3; (**c**) Nissan Leaf; (**d**) Tesla Model 3S.

5.2. 50% Iniatil SoC Tests

Assuming that a car starts with 50% SoC, results change a bit. Both Tesla cars need at least two stops at 90 km and 242 km from Toronto with a total charging time of 1 h and 6 min for Tesla Model 3 and 1 h and 9 min for Tesla model S. In addition, the other two cars need an additional stop more than before. Nissan Leaf needs three stops with about 2 h of total charging time. Figure 9 represents the number of stops per kilometre considering different types of vehicles with 100% SoC.

Analysing final results, it is observed that, with a starting SoC of 100%, there is little difference in time between a Tesla car and a standard petrol/diesel vehicle (considering that during a trip everyone needs some stops). With a fully charged SoC at the start, there is need for only one stop. It is noteworthy that we were working on the assumption of an ideal situation where charging points are always available and ready to use. With a starting SoC of 50%, total travel time increases by 10% with respect to total travel time of a standard diesel or petrol car. Considering Nissan Leaf results with a starting SoC of 100%, they are almost acceptable. Total travel time is less than 6 h in ideal conditions. Unfortunately, both tests (with 100% starting SoC and 50% starting SoC) are not acceptable for Kia Soul. BMW i3 results are comparable with KIA Soul one. Figure 10 represents charging time comparisons for different type of vehicles (blue bar is 100% SoC, and orange bar is 50% SoC).

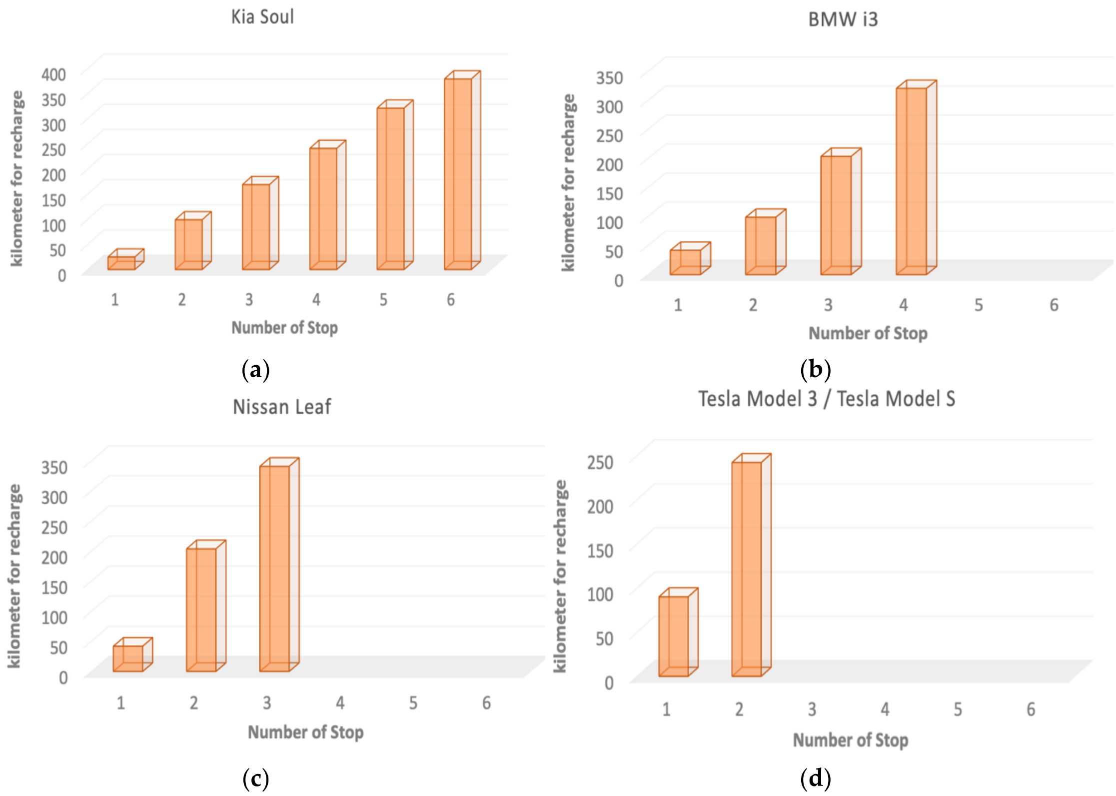


Figure 9. Number of stops as a function of kilometres travelled for different types of vehicles with 50% SoC: (**a**) Kia Soul; (**b**) BMWi3; (**c**) Nissan Leaf; (**d**) Tesla Model 3S.

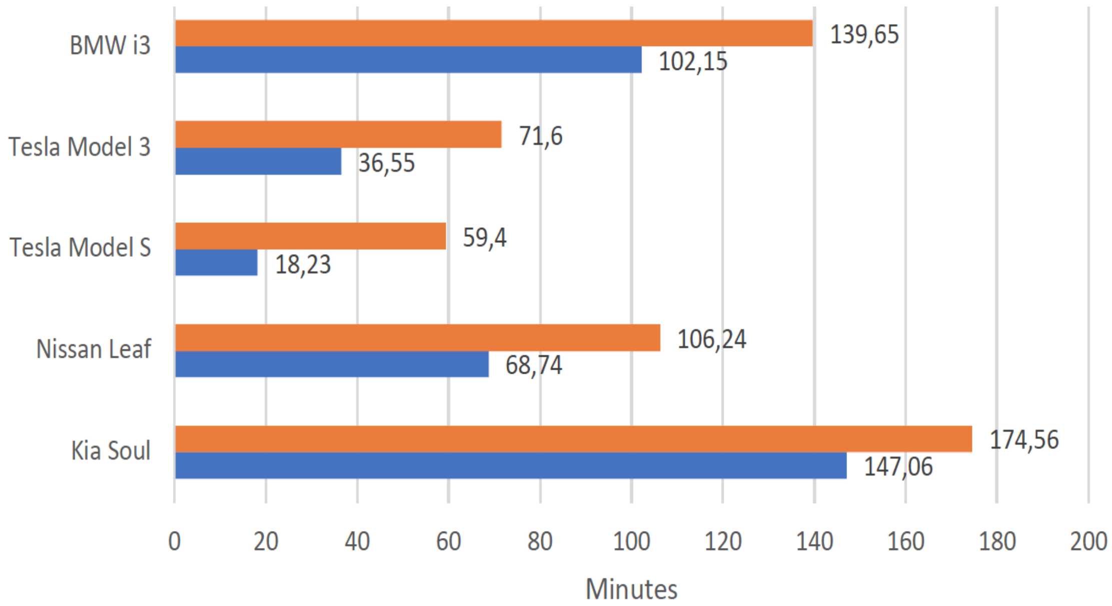


Figure 10. Charging time comparison for different types of vehicles and SoC: blue bars for 100% SoC case; orange bars for 50% SoC case.

This result is continuously changing. It is instructive to imagine a new configuration of architectural design of Tesla Supercharger v3 that will take peak rates of up to 250 kW per vehicle. At this rate, a Model 3 long range operating at peak efficiency can recuperate up to 120.7 km (75 miles) of charge in 5 min and charge at rates of up to 1609.34 km/h (1000 miles per hour). Following from the great variety of designs and options evolving in the market, it is accurate to state that use of the EV is continuously growing around the world with a potential for even more growth, variety, and versatility in the coming years.

6. Conclusions

The objective of this work was to develop an algorithm for optimizing recharging stops during a complete trip in an EV from Toronto to Ottawa (Canada) along Ontario's Highway 401. Through simulations and analysis of data, this paper investigated the difference in terms of times between selected EVs, namely BMWi3, Kia Soul, Nissan Leaf, and Tesla Model 3S. The study considered a smart highway focalizing on the actual distribution of the charging stations (CSs). The results confirmed the possibility to make this trip using EVs. Obviously, considering different types of vehicles, it is necessary for the vehicle to arrive at the destination. It was found, for example, that the Tesla EV required making only one stop, and the charging time was typical of such a long journey. Times and number of stops along the trip were found to vary for the different vehicles, for instance, for the Kia soul EV, the situation was different compared to the Tesla EV in that it required more stops. In addition, the defined methodology and the developed algorithm can be applied to any case study and may serve as an effective tool for both simulation and optimization of recharging stops, making the most of the charging stations presented in the specific area. Furthermore, the tool could be utilised to evaluate the possibility of strategically adding new charging columns where it is needed.

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