4. Model Modification

4.1 Overview of Advanced Models

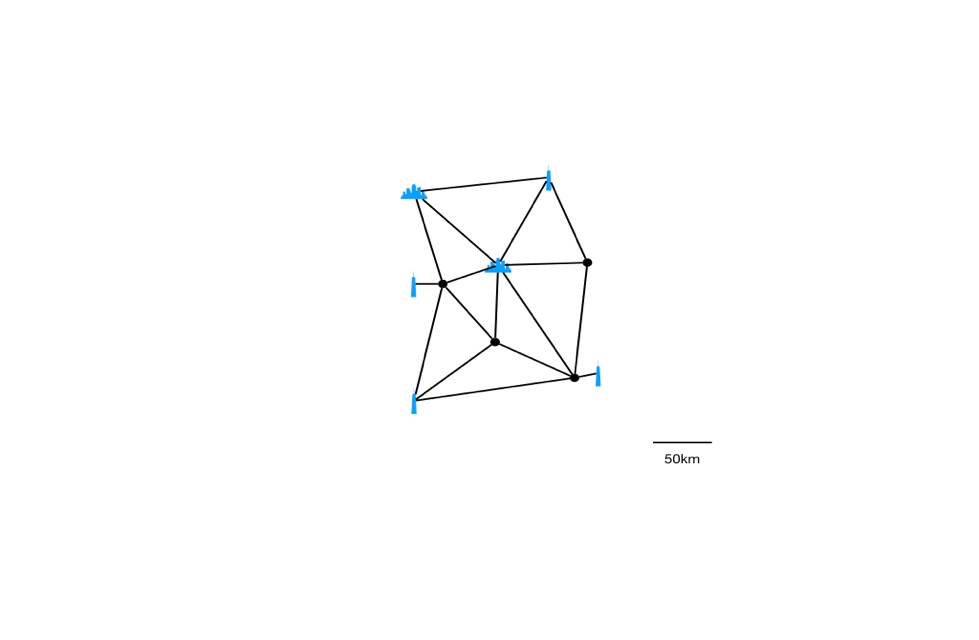
Comparing to the basic model based on America, the total number of current and coming soon charging stations are already sufficient for 100% cover of electric cars. Since different country has variant geographic features and population distribution, the basic model and algorithm we create for America might not also suit for other countries. Hence, our model needs further modification by considering some key factors.

Country’s population distribution and local highway network are considered as main factors for modification of model one. When analyzing model one, we found a linear relationship between population in a state denoted x and number of its current charging stations, y, by calculating their correlation coefficient

and = 0.895, which showed a strongly positive linear relationship by comparing with , 0.28. Also, the classification of urban, suburban and rural areas is mainly based on local population and larger population means more potential purchasing. Thus, we list population density as the first factor. Moreover, charging stations are supposed to be on the main roads specially for highways due to more demands for long distance travelling and because of geographical influence, there would be more roads in cities and less in mountainous districts, so the second factor we consider as the current local highway routes.

We have two models that respectively focus on usage rates of stations and their rationality if they were built followed as our design, Hinge Distribution Trail model (HDT) and Shortest Route Preference model (SRP). In HDT model, the charging stations are distributed due to traffic hinge distribution. Without considering how long it will take for a vehicle to reach destination if charging is required on the way, stations are placed in furthest hinge point relative to the current position as long as they could support the vehicle’s power. The second model is based on the shortest route so that electric cars could be charged on the way to the destination as soon as possible.

Given a highway network of a country, we locate the main traffic hinge and districts. We simplify them to cross lines and points shown below



**Fig.1** A simplified highway network map in which dots mean the traffic hinge and blue marks represent provinces in different level.

As our assumption, we determine a constant cursing distance . As for the travel distance, we determine it as , which is obtained following the highway network from start to the end place. Our main concerns now are to set charging stations when reasonably and as our models are proposed, we create two methods to place stations. After that, we simulate as condition of several countries with different landscape and population distribution to evaluate its sensitivity for further classification and conclusion.

4.2 Population Distribution Trail Model (PDT)

The method could be briefly concluded as follows, denote :

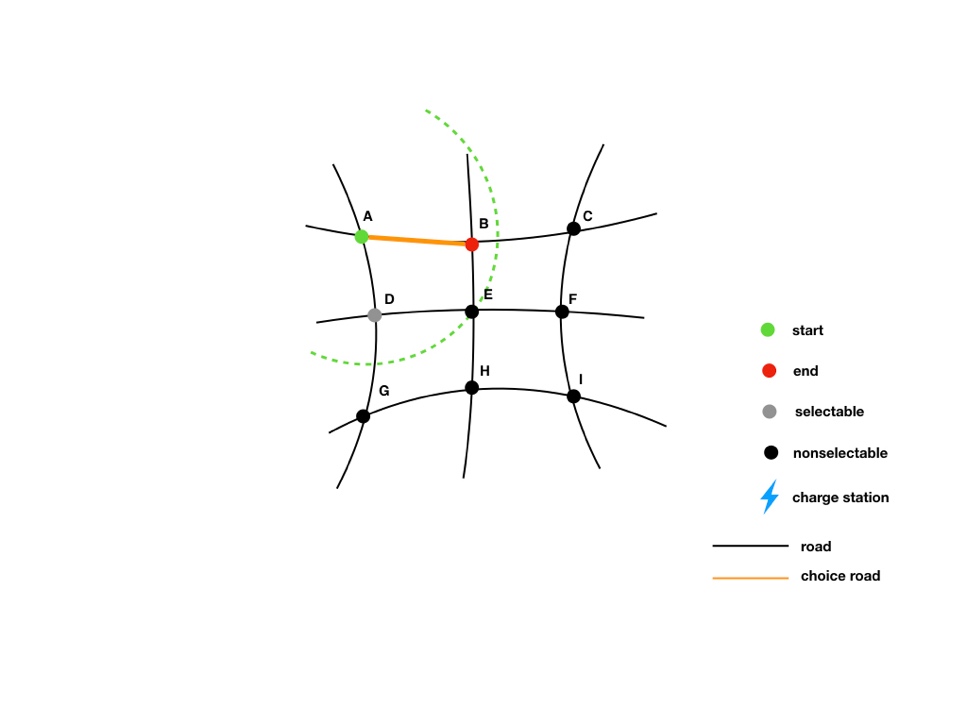
∆ Condition: and start with full electric energy, which could be treated as a station;

∆ Selectable placements of charging stations: chosen by network points within ,

∆ Stations placement: at the furthest point to the current start point that within

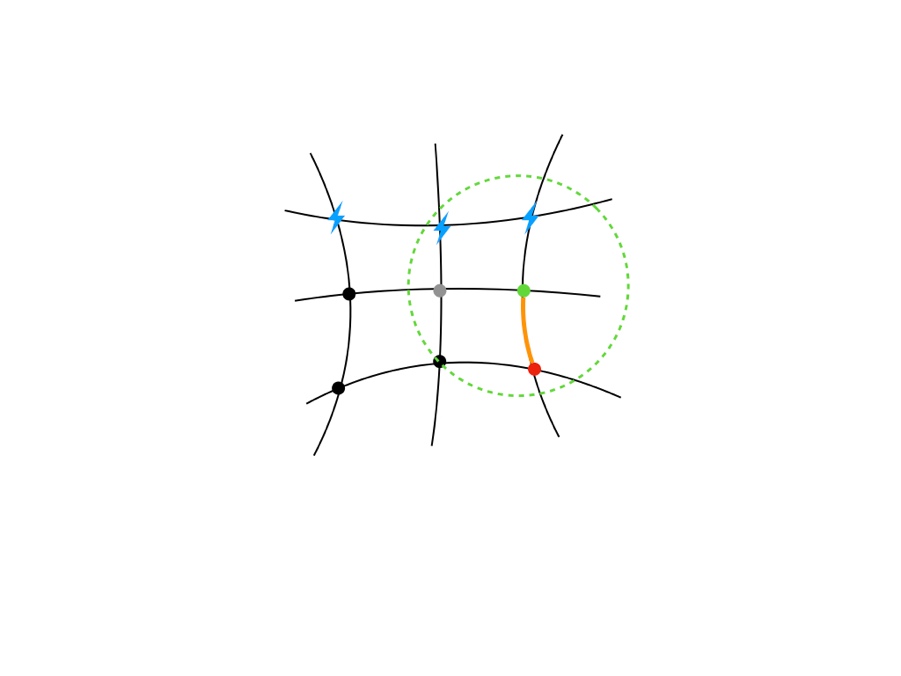
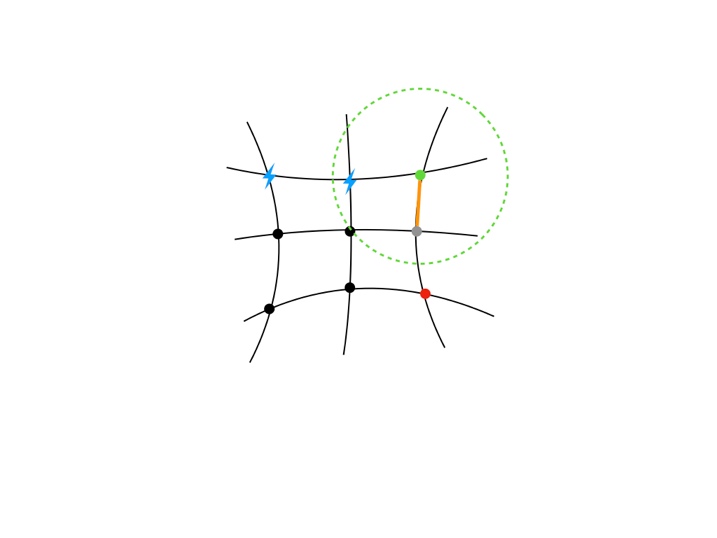
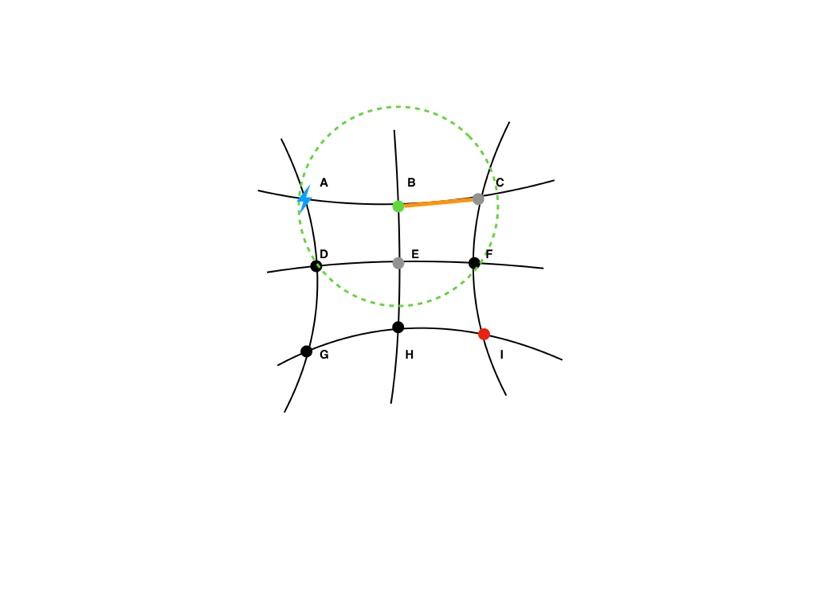
∆ Repeat the previous process until , ;

The factors affected in this model is cities and traffic hinge position and distance from each other. In corresponding algorithm, the cities’ position or coordinates and distance between each two cities need to be recorded. Create a simplified highway network map as below. Black dots represent cities and traffic hinges demoted from A to I. Green circle has radius of cursing distance and destination traveling distance is randomized. Here we give an example when allocating the furthest point I as destination. Green dot, red dot, grey dots and blue flash represent start point, temporary end point and selectable placements for stations respectively. These denotes would be used in the following discussion.



**Fig.2** Simplified Highway network map. Within the radius (green circle) , we mark by grey dots to present selectable placement for charging stations. Here we have point A as start point and B, D as selectable placement. Then we choose one of selectable points as station, also for an end point, B. Notice that, when there are several selectable placements, we choose the relatively farthest point to place station.

The whole process could be represented by Figure 3 below.



**Fig.3** Three pictures from left to right in order show the process to place the charging stations. The final result is placing 4 stations, A, B, C, along the way to destination I.

4.3 Shortest Route Preference model (SRP)

Instead of considering population distribution only, in SRP model, after the destination has been fixed, we determine the shortest route on highway network first and then only consider building charging stations along it. In this case, in spite of cities coordinates and distance between each two are needed, we also use Manhattan Distance to locate the points in a city’s neighbourhood. The whole process is similar to PDT model:

∆ Condition: and start with full electric energy, which could be treated as a station;

∆ Determine the best route: comparing distance between start point and destination in

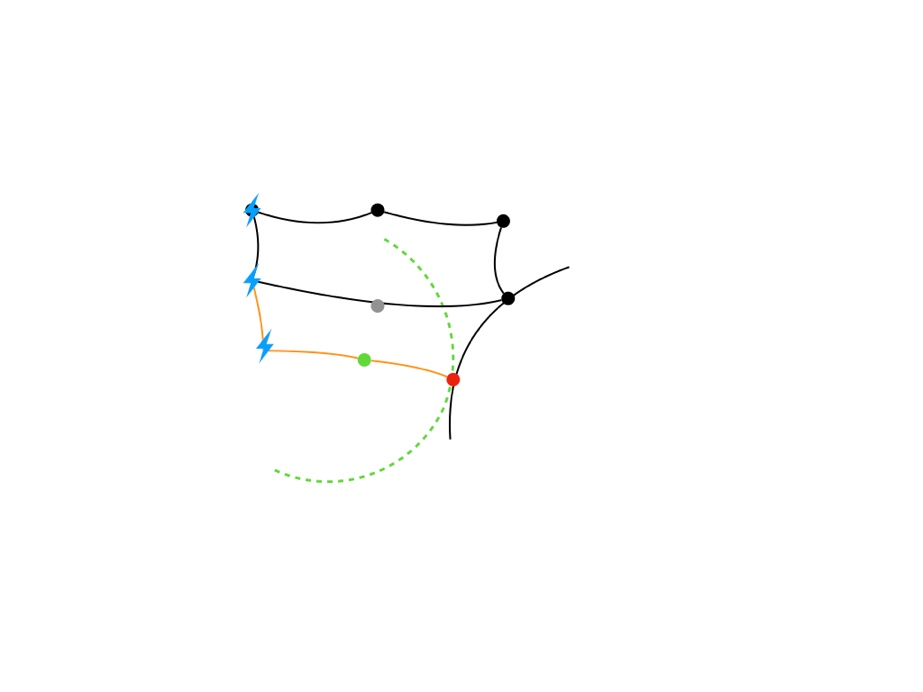
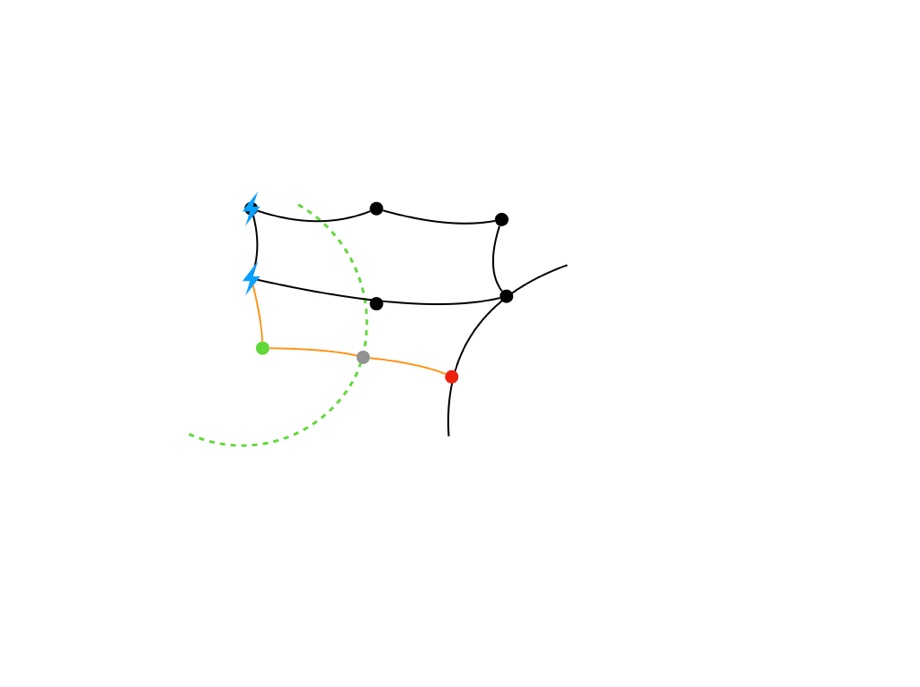
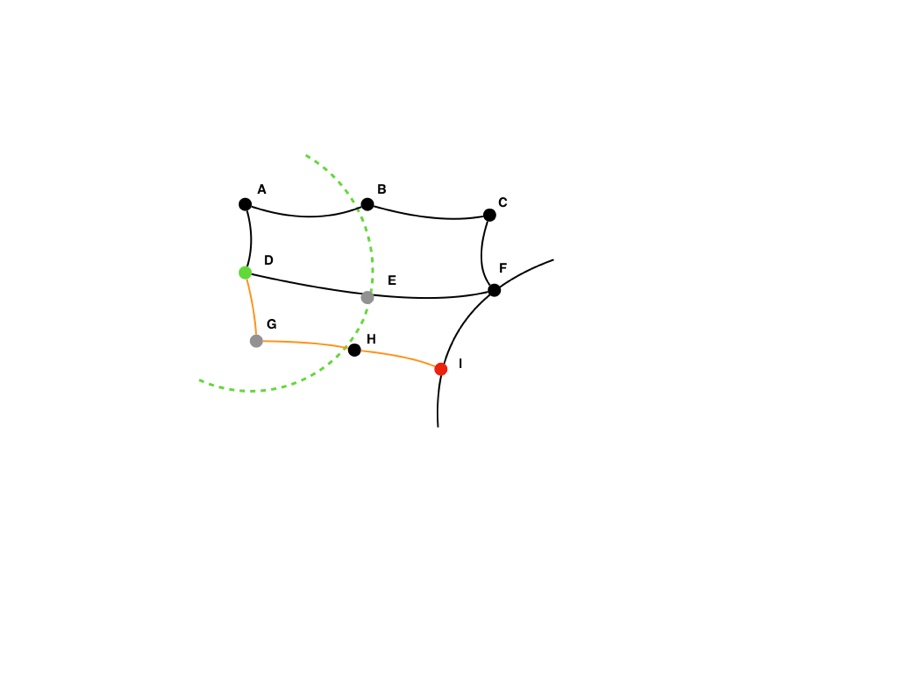
different way by Manhattan Distance;

∆ Selectable placements of charging stations: chosen by network points on the chosen route

within ,

∆ Stations placement: at the furthest point to the current start point that within

∆ Repeat the previous process until ,;

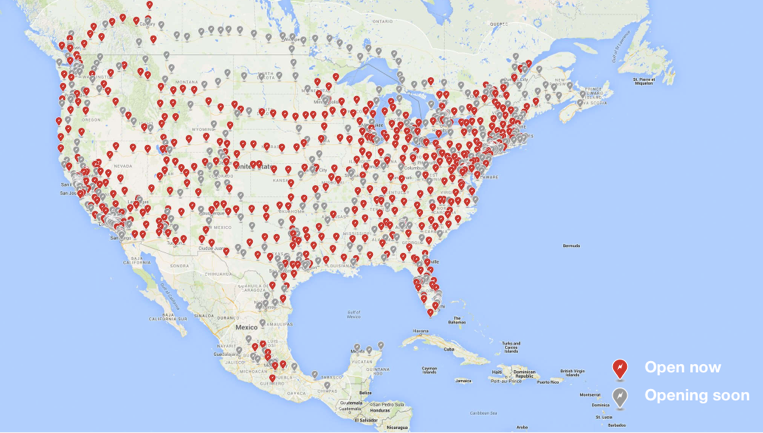


**Fig.4** Three pictures from left to right orderly show the process to place the charging stations. At the beginning, the shortest route has been chosen, shown by orange in the figure. As a result, the chosen points to place stations are A, D, G.

4.4 Rough Evaluation of PDT&SRP Models and Revisit Current Situation of America

Intuitively, two models are modification of model based on Tesla charging stations in the USA. We generally consider the population distribution and highway network as main factors. However, there are many other influential elements to discuss, such as GDP in different district, average electric vehicle holding and other production of high technology that would influence demand for charging stations. These factors would be discussed in the later sections with the electric cars’ evolution specific to one example country.

Revisit the current charging stations in the USA of Tesla, data and figure show that most stations are built near highways and there are more stations in states holding larger population such as California and New York. Apparently, the distance and population density are two main factors Tesla considers that influence charging stations distribution. Therefore, the models we create are reasonable.

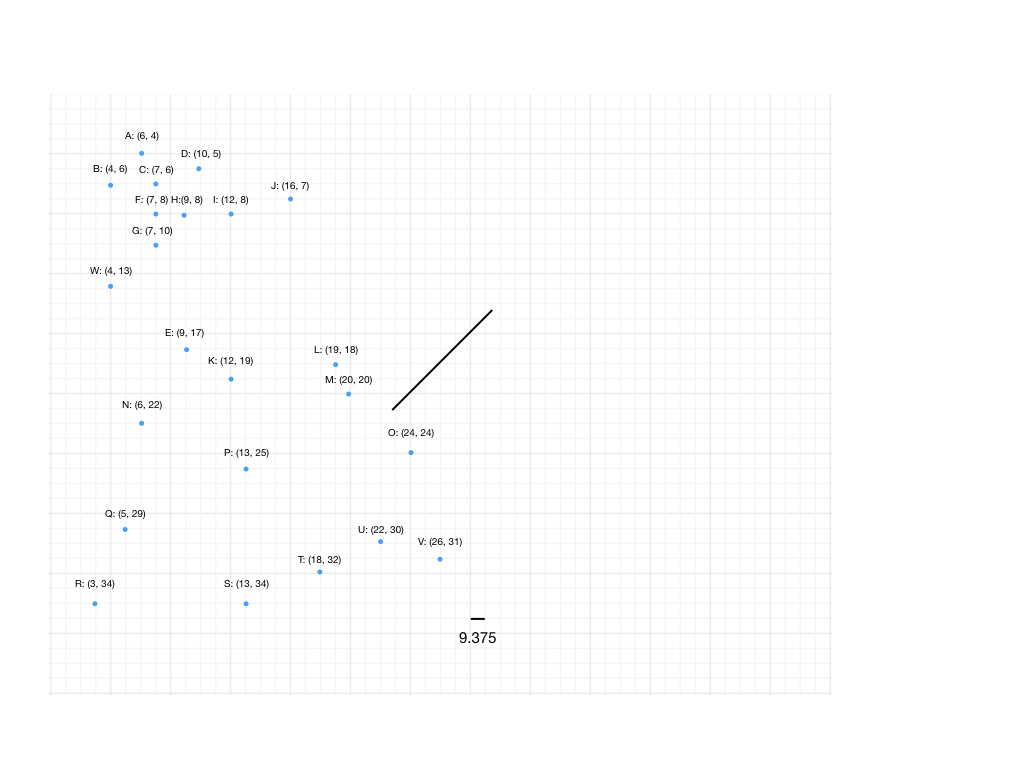
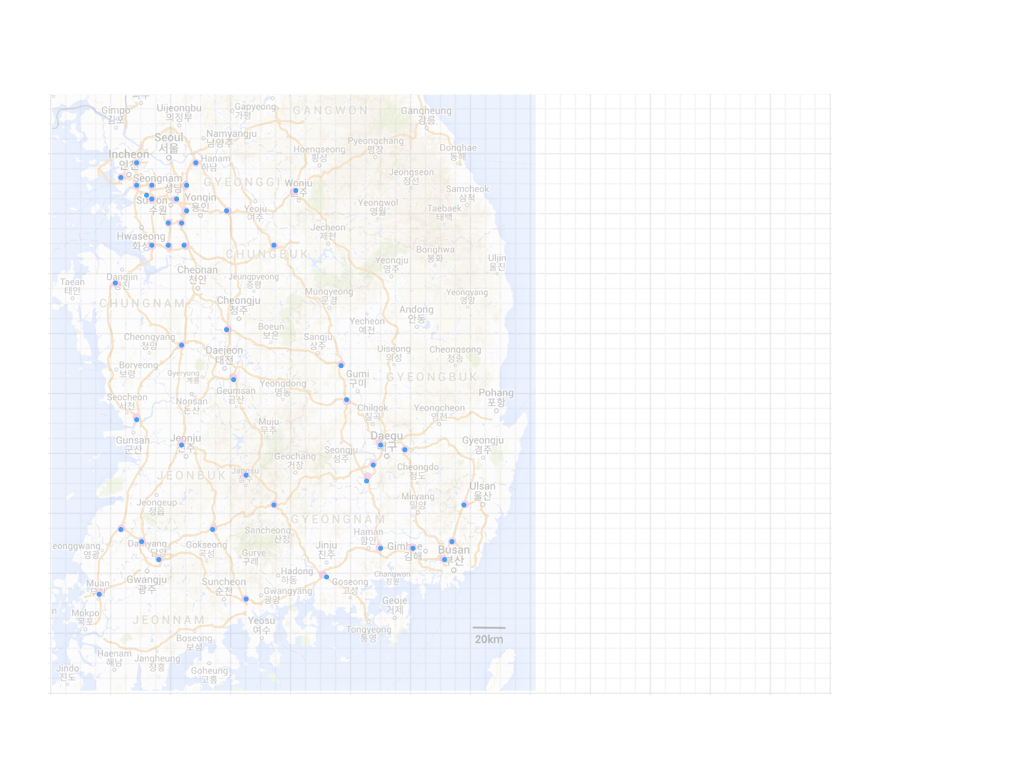


**Fig.5** The current charging stations in the USA of Tesla.

5. Model Testing

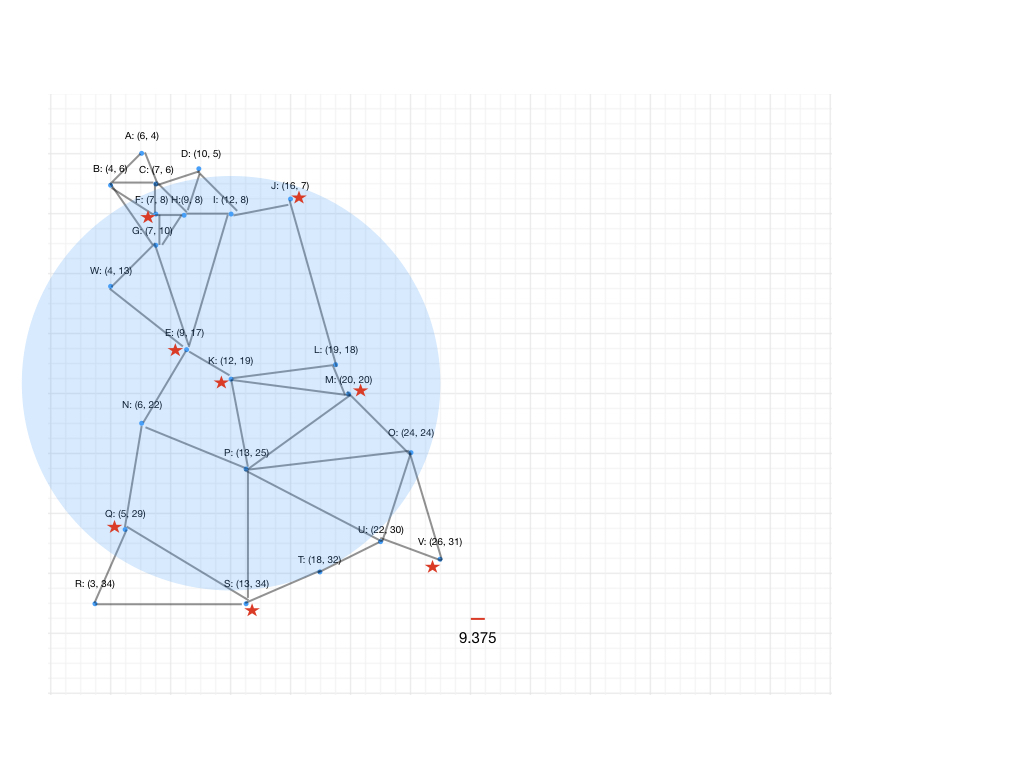
5.1 HDT Model Testing and Evaluation Based On South Korea

At the beginning, we choose all traffic hinges from highway network. Adding grid to the origin map, we locate all considered hinges as shown below with their coordinates.



**Fig. 6** Hinges map with coordinates based on highway network.

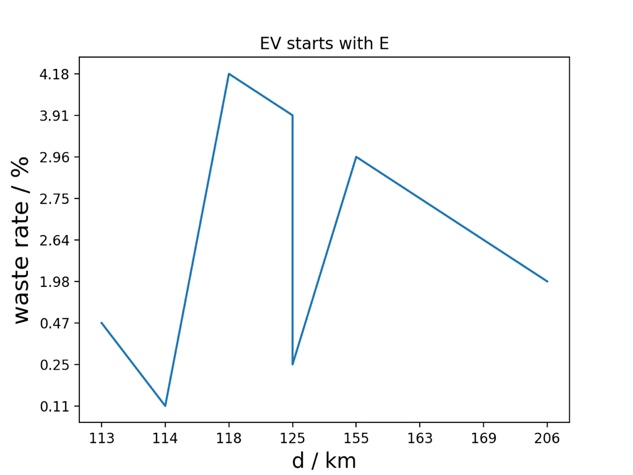
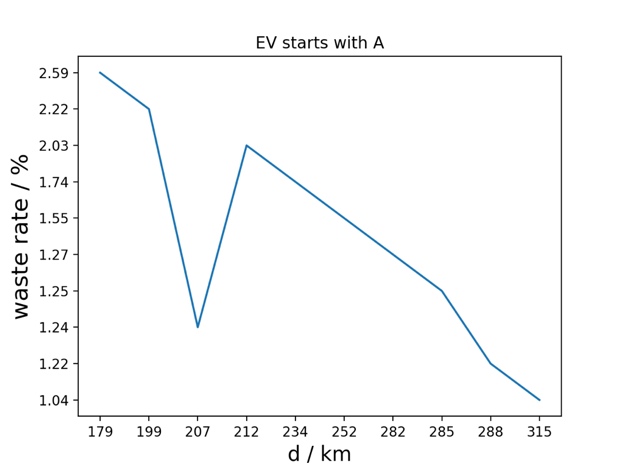
Using Manhattan Distance algorithm to determine each point’s neighbourhood, we connect those hinges by considering their relative shortest distance. The simulation is finally generated according to the following map.

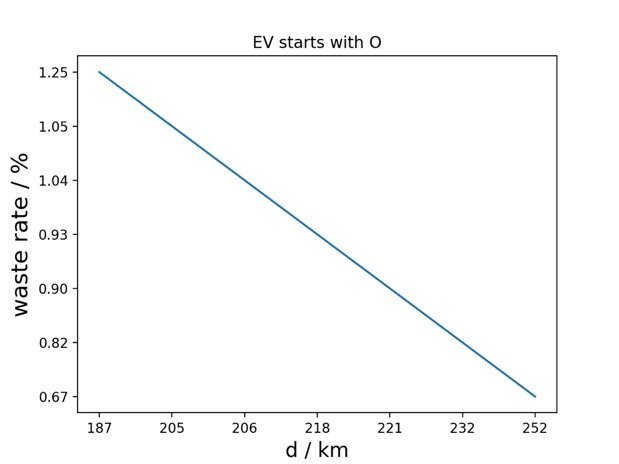
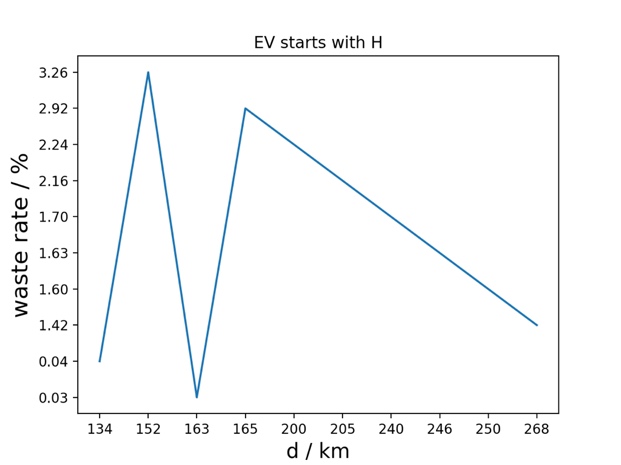


**Fig. 7** Our charging station route design based on HDT model. Here a length of a grid is 9.375 in km. Red stars represent the stations’ positions.

Numerical method we sued for rationality of our HDT model on South Korea is evaluating the difference between the travelling path and the distance between two places. Basically we chose four points as start respectively from the most crowded province such as Seoul, less crowded, mountainous district such as Gyeongbuk and a central place such as Daejon. We evaluate waste rate, defined as,

where is travelling path and is the distance between two places, with relationship of different , which means different destination in our simulation. The result could be seen as below.





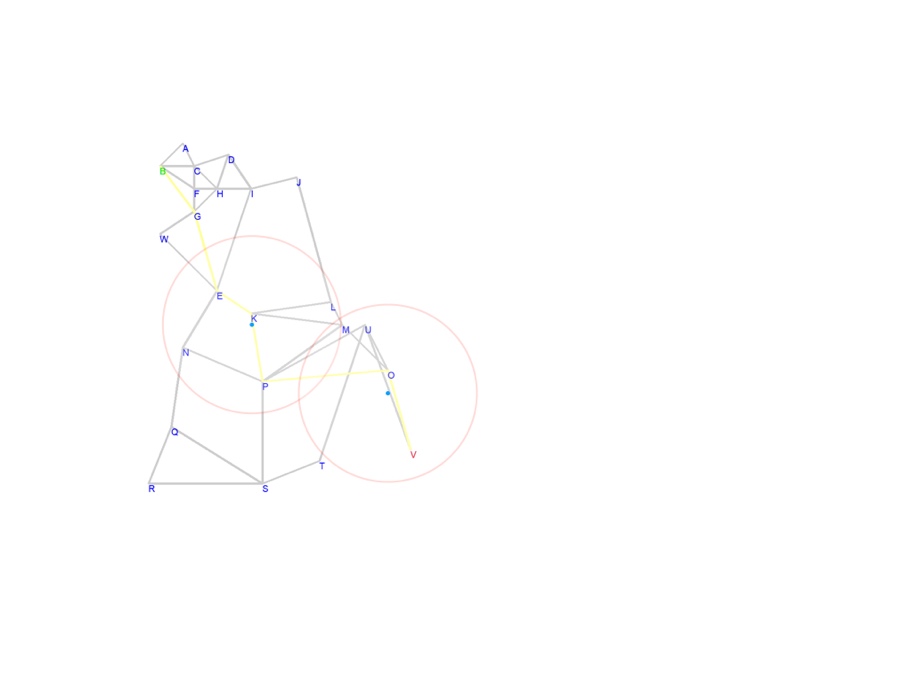
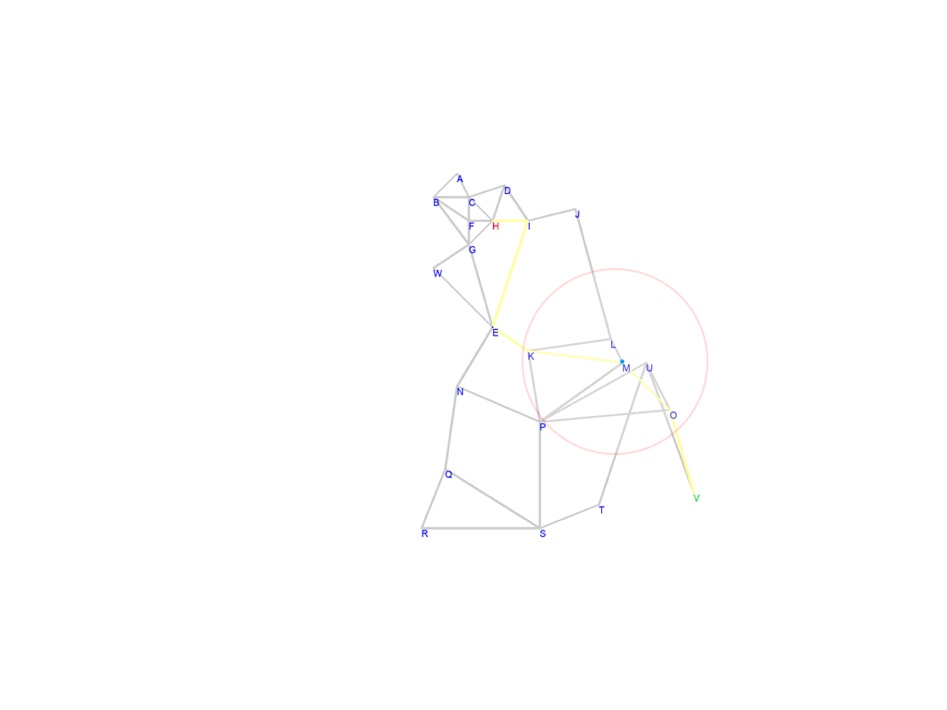
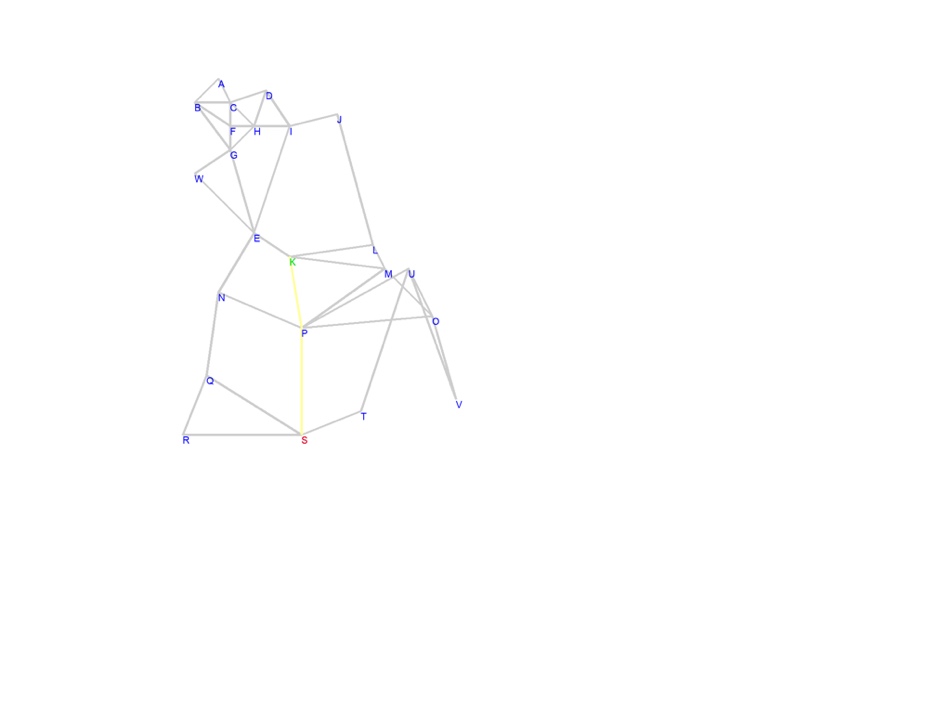
**Fig. 8** Four charts orderly show the relationship between and waste rate considering different starting point.

It could be seen that as is getting larger, the less waste path a car would travel. For a province that has high population density and rich traffic network, such as point A, it would waste less travelling for reaching more remote places such as R, S, V. For place like O that not many hinges to place stations, it indicates a standard negative linear relationship between waste rate and .

This indicates that our HDT model is not suitable for small country or country who has short distance between each two cities. Since our model is based on local highway network and stations are built up at traffic hinges, if two cities are close, which means surrounding traffic hinges are close, our algorithm might cause detour.

5.2 SRP Model Testing for South Korea

Here we briefly introduce the application in our SRP model. The choosing process is similar to HDT model and the only difference is that in this model the first step is fixing the relative shortest route and then considering build up stations as the furthest hinge point. The whole process could be shown as below.



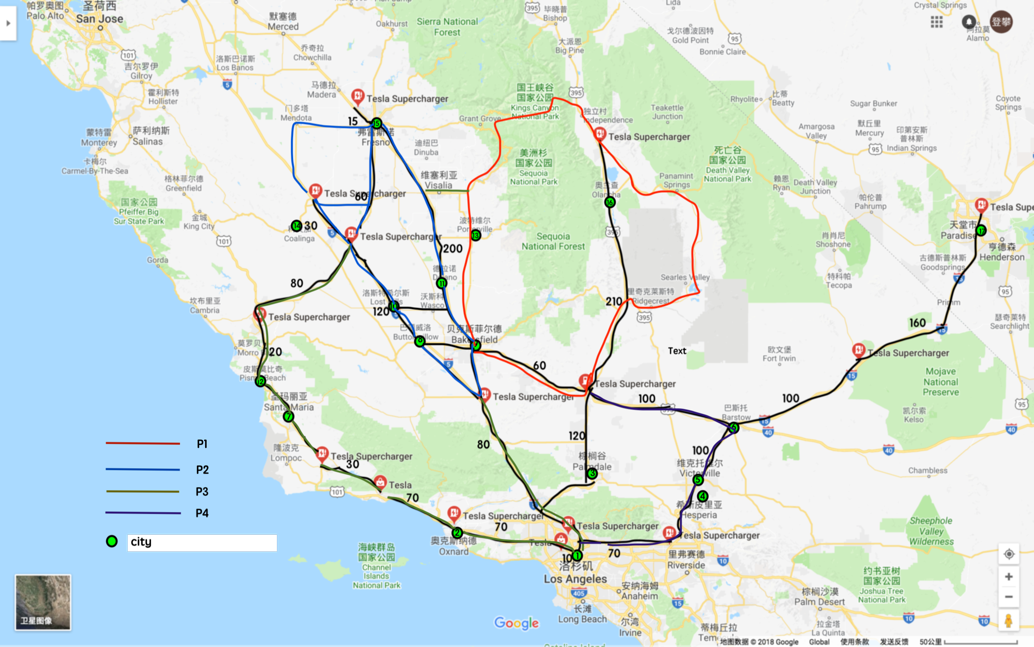
**Fig. 9** Three examples of choosing the shortest route. Yellow line is shortest route chosen for each start point.

The figures are shown above are three examples of how to determine the shortest routes for a car. Example one is route for R to S. The second figure is for H to V and the last one is for B to V.

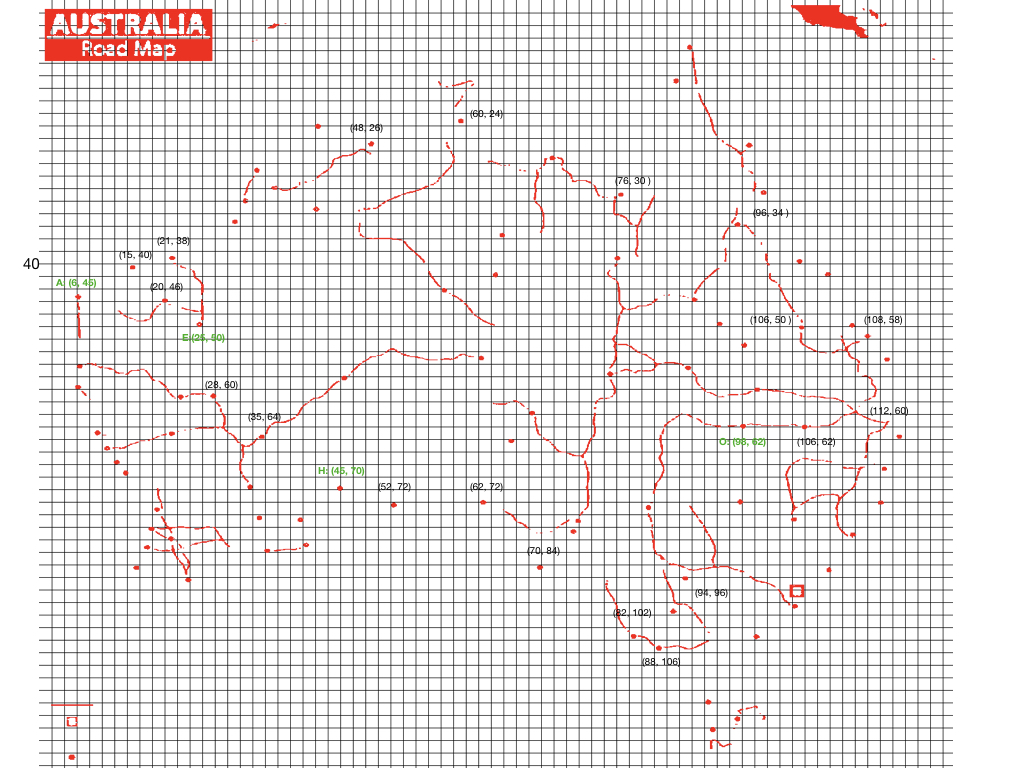
5.3 HDT Model Testing Based On Australia

As mentioned before, a country’s landscape and traffic hinges distribution also influence the efficiency of charging stations which is evaluated by waste rate. The second test is based on traffic network of Australia. By choosing some start and end points, we repeated same process for comparison.

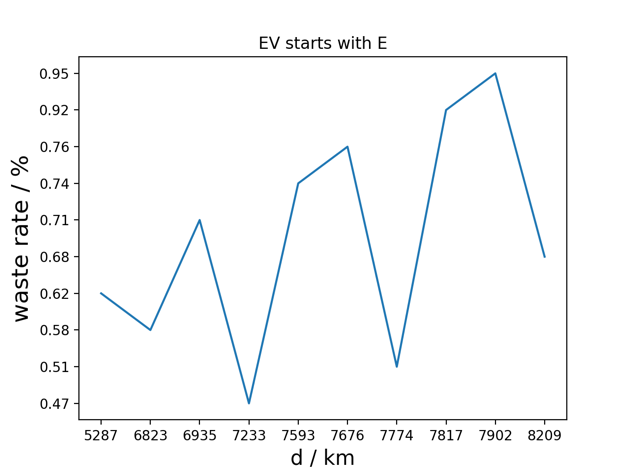
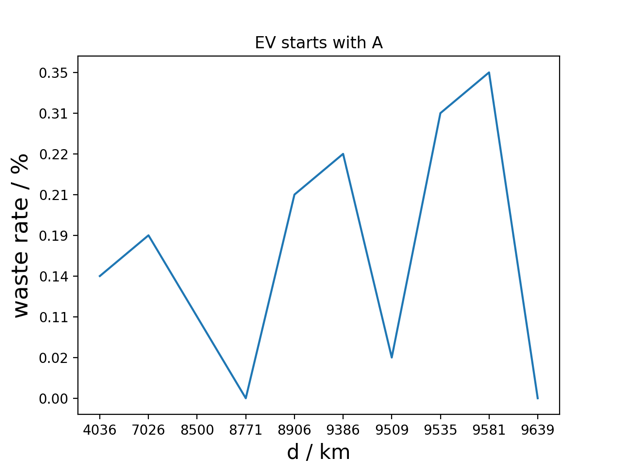
First we present the traffic hinge map we set for later simulation.

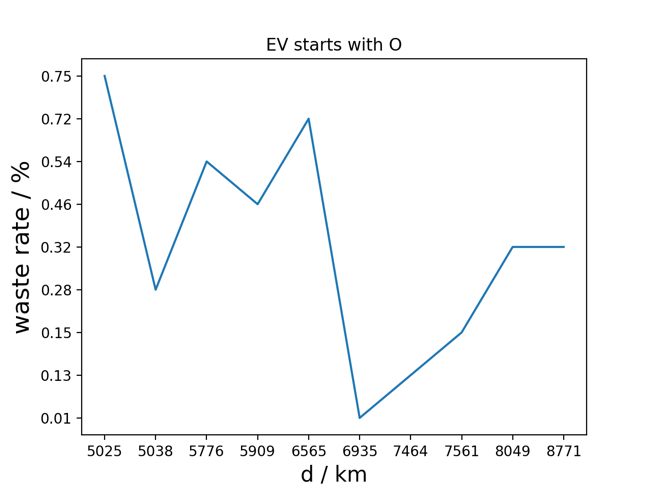
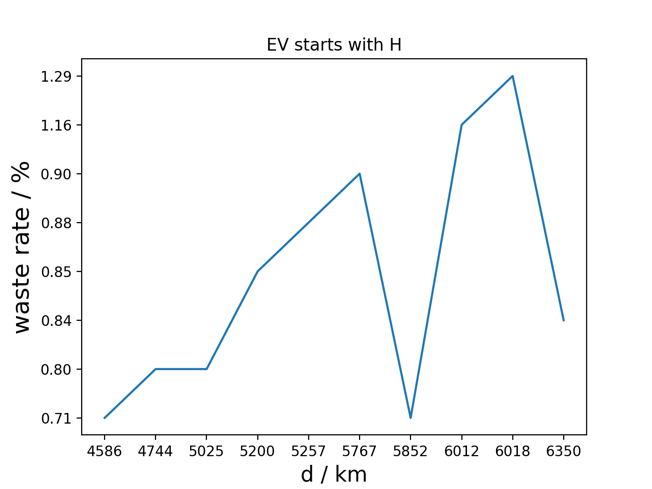


**Fig. 10** Overview of traffic network of Australia.



**Fig.11** Traffic network and hinges we fixed for Australia and later simulation.





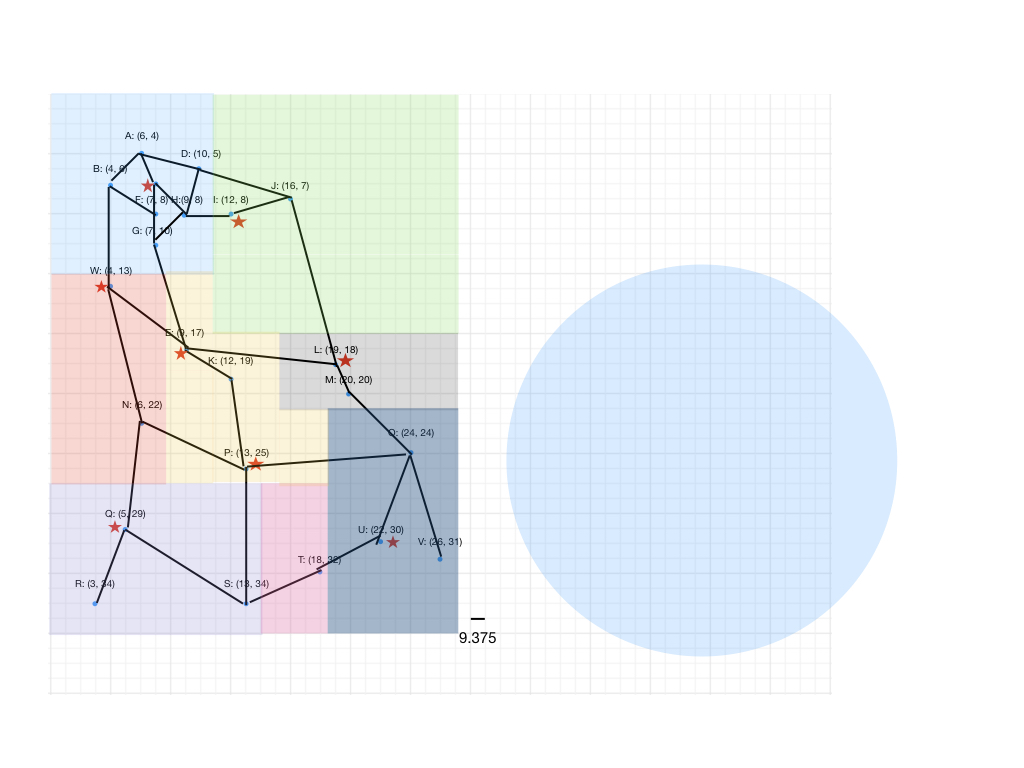
**Fig.11** Four results for different start hinges chosen.

It could be seen that waste rate fluctuated a lot as destination distance is increasing but the general result shows that our model works well in both of these countries but it suits better for Australia. However, one point to pay attention to is that since the property of electric vehicle is also important, we propose that when constructing network for the charging stations, fully consider the cursing distance and build up stations as our model does.

6. Other Models

6.1 Neural Distribution Network Model (NDN)

From example of South Korea, we discover that the country who has intuitive traffic hinges distribution, HDT model is not very suitable. In the Seoul area, there are dense hinges and high population, then there would be more selectable stations placement around the start point in Seoul but the relative furthest one might cause detour. In this case, we construct another model that is simply based on latitude of hinges. We split hinges into several groups due to their positions and belonging provinces.

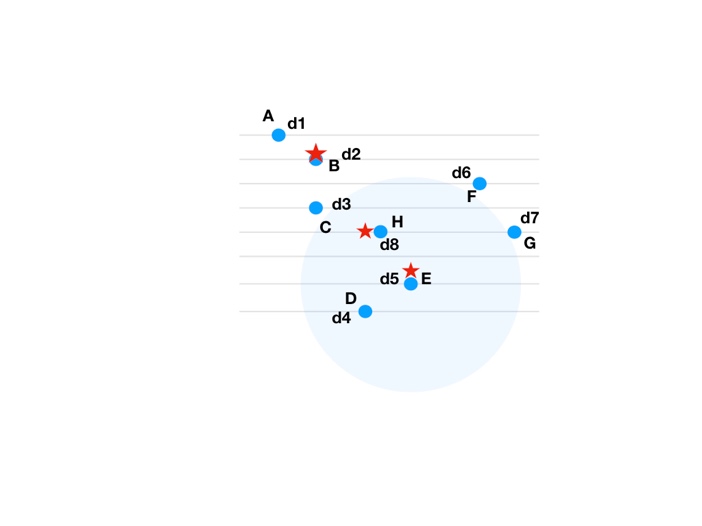
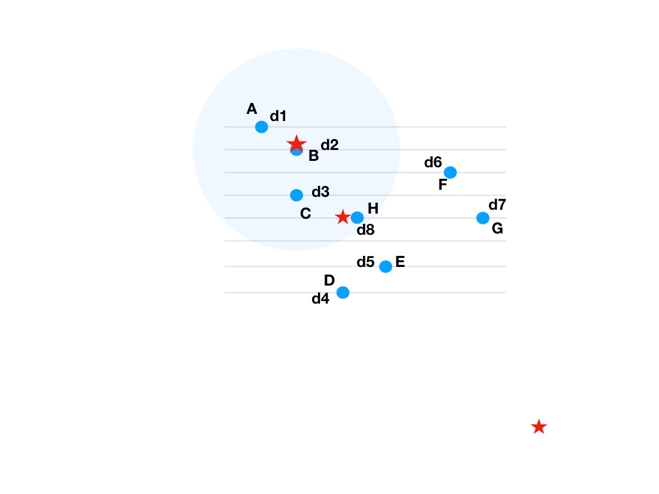
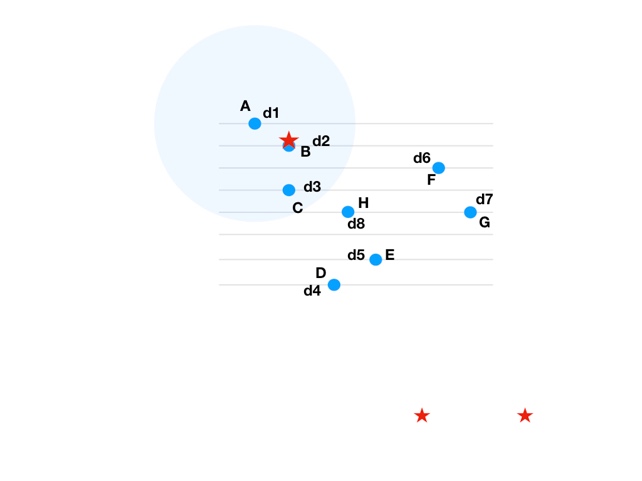


**Fig. 10** The network of NDN. Different colour continents represent different hinge groups.

The main idea is that within each group, since hinges are separated in groups by province, the more crowded the province is, there are more likely to be dense hinges. Thus we connect all hinges from above to the bottom vertically and connect neighbour hinges across provinces horizontally. In the blue area due to high population density and more travelling, we connect hinges like a neural network, so that route choosing is more flexible and waste rate could be reduced.

6.2 Population-City Base Model (PCB)

Generally, instead of considering highway network and hinges, we now could choose cities as our candidates for charging stations. The new network then will be created by the city location. Moreover, when several cities are within cursing distance, we compare each city’s population density, denoted by , and then choose the city that holds the largest density as our station placement.



**Fig. 9** From point A to D, the network constructed by the charging stations, in red stars.

Start from city A, within the cursing distance, represented by the range of blue sphere, we have B, C two candidates, assume d2>d3, we choose B. Repeat the process until the destination is included in cursing distance sphere.

7. Evaluation and Network Growing Plans

7.1 Strengths

Our models are mainly based on local current highway network which is already considered by the country landscape and richness of traffic. It could be seen that, placing charging stations at hinges of highways could increase usage of charging since travelling routes depend on main highways or roads and hinges apparently would have large traffic flow. Therefore, our models follow the traffic trend.

We also consider the waste route if travelling path is based our design. In aforementioned numerical analysis and plots, HDT model is more suitable for larger area country that hinges are less crowded and crossing states with larger distance. If the travelling path could be saved efficiently, the less demand for charging stations and better experience for users. In our first America model, we could see that in principle, for one country, the stations people need in total are much less than reality. This indicates that after satisfying basic demand, more stations could be set up in crowded places and metropolis. In those big cities, there more resources and financial support for the development of charging stations, which would also facilitate the growth of electric vehicles.

7.2 Weakness

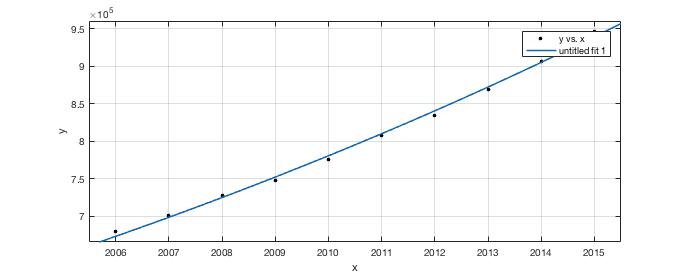
At the beginning, we searched lots of data for a country such as its landscape, its traffic network and population. Also we predicted for its population increasing situation and used average cars holding percentage to determine the number of vehicles. These estimations might cause difference when applying to reality. The models we construct are in principle. We simplify the countries map to do analysis and reduce the complexity of highways. We convert curve to straight line to compute the distance which might cause mistakes and make it less realistic.

7.3 Plan of Development of EV’s Network

All models are based on different criteria that considers less waste rate and higher usage possibility. Since the construction cost is another factor to influence the development of electric network and its coverage, we do need to pay attention to the local demand for charging stations. In other words, begin from zero slate, we could consider to build up several charging stations according to the electric cars sales-planning. We distribute stations following planning sales number in positive proportion with local GDP to different areas.

We propose that in the process of evolution of electric cars, the total number of charging stations is meant to be determined by the sales-planning. The placements could be determined referenced by local highway network first and then the number of stations in each area depends on the local GDP with a positive relationship.

Considering there are numerous technologies that are changing our lifestyle and there more alternatives for travelling. The development of electric vehicle would be influenced by other advanced transportation but since the growing of other technologies takes time to enter the main market, so in near future we assume the main trend would be increasing in exponential way.



**Fig. 10** Passenger cars in use in recent years.

By searching for average GDP and EV production, the total trend of EV increasing trend could be concluded as

where t is time in year and N is prediction of total number of EVs.

8. Conclusion

According to previous numerical analysis and model testing, we conclude that main model HDT is suitable for country with large area. It could basically reduce travelling waste path to offer a reasonable experience and construction idea. Other models, SRP is another further modification based on both model one and HDT. When considering the hinge position, we also add shortest route as first factor and condition. Then based on these conditions, we could make sure the waste rate is almost zero and also all charging stations could support any path to the destination.

For the future study, we propose simulations for other models and based on different countries who have different population distribution and landscape. Also, when comparing results, we could consider the waste rate and its relative usage efficiency according to surrounding area’s traffic flow to test the necessity. Then when analysing the results, we can compare each models’ strengths and weakness with simulations on different countries.