TOUR-AND-CHARGING SCHEDULER BASED ON (N+1) TRAVELING SALESMAN PROBLEM MODELING

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Abstract – Tour-and-charging scheduling for DC chargers is modeledas (*n*+1) traveling salesman problem, where 1 out of *m* chargersis added to the set of *n* given destinations. To cope with the executiontime explosion according to the more deployment of chargers, thispaper designs a heuristic by which just a small set of chargersare investigated. To narrow the candidate set, our scheme sorts thedestinations according to the distance from the start point and thenpicks just a limited number of chargers closest to each destinationone by one. The restriction avoids the containment of candidateswithin a small area. The experiment result, obtained by means ofa prototype implementation on a real-life geographic distribution,reveals that the proposed scheme can find a solution comparable tothe optimal one with 5 candidates, the gap not larger than 2.7 % forthe given parameter setting.

Keywords – Electric Vehicle, DC Charger, Tour-and-Charging Schedule, Traveling Salesman Problem, Response Time.

I. INTRODUCTION*

The deployment of DC chargers is good news for EV(Electric Vehicle) drivers, as the charging time is significantlycut down to tens of minutes [1]. Yet, the range anxiety problemis not completely solved as their availability is not so muchsatisfiable as gas stations and the driving range still remains ataround 100 *m* in practice. Hence, it is necessary to make anefficient tour plan including charging [2]. Taking into accountDC chargers and the usual daily driving distance, chargingis needed at most once. Here, a mis-selected charger mayextend the tour distance and time, sometimes require onemore charging. After all, tour-and-charging scheduling is theprocess of finding an appropriate visiting sequence for *n* givendestinations and 1 out of *m* DC chargers. It is a variant of thewell-known TSP (Traveling Salesman Problem), and the timecomplexity of such (*n*+1) TSP, on our definition, will growaccording to the increase in *m*, that is, the wider deploymentof DC chargers. The number of destinations, or *n*, will notchange in each area.

Basically, the complexity of the classic TSP is $O(n!)$, asthere exist *n*! sequences for n destinations to visit. The optimalexhaustive search investigates the cost of each sequence tofind the best one. The cost can be distance, time, batteryconsumption, and the like. Our EV scheduling has a constraintthat the number of charging operations should not exceed 1.Many suboptimal but very efficient algorithms are available forthe TSP, including genetic algorithms, Lin-Kernighan scheme,and others. For the (*n*+1) TSP, we can put each DC chargerto the set of destinations and run a TSP solver with (*n*+1) destinations. After doing this step for *m* times, the best onewill be selected. However, if *m* gets too larger, it is necessaryto narrow the scope of investigation, replacing *m* by *m*′, where($m' \ll m$). It may sacrifice the optimality, but with large*m*, the difference between the optimal and the suboptimalsolutions will be smaller.

II. SCHEDULER DESIGN

Figure 1 describes what this paper is focusing on. In thefigure, there are 5 destinations from D_0 to D_4 and 6 chargersfrom C_1 to C_6. D_0 is specially numbered to denote it as thestart point of the trip. Each feasible schedule is associated withsingle charger. We define the best charger as the chargerassociated with the best schedule. The second and third bestschedules can be also reasonable solutions. Hence, if we runthe TSP solver only for a small number of chargers whichcan be one of them, the execution time will be much saved.To this end, each charger is ordered by a certain criteria, andonly m' not 6 ones will be taken into account. Additionally,it must be mentioned that if battery depletion is anticipated,this sequence will be discarded.

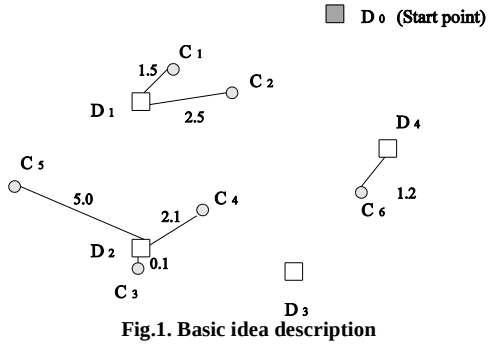


Fig.1. Basic idea description

Our previous work has sorted chargers by the distance toany destinations, creating the ordered list of (C_3, C_6, C_1, C_4,C_2, C_5) [3]. Then, if the charger

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next to the start point isselected, it reduces the possibility to find the best schedule.Another work gives the precedence to those chargers closeto the destination farthest away from the start point, namely,D_2 [4]. This procedure creates the ordered list of (C_3, C_4,C_5, C_2, C_1, C_6), even though the distance from D_2 to eachcharger is not presented in the figure. This scheme alleviatesthe above-mentioned problem, but the best chargers can beindependent of such farthest destination. To complement bothschemes, this paper limits the number of chargers selected bya single destination. Hence, even if C_5 is the third closest oneto D_2, it will not come in the third place, if the limit is setto 2. The farther a destination, the more precedence is given.Hence, the proposed scheme creates the ordered list of (C_3C_4, C_1, C_2, C_6, C_5).

III. PERFORMANCE MEASUREMENT

This section exhibits the performance measurement resultsobtained by a prototype implementation. The cost matrixconsists of the distance between each pair of two tourist spotson Jeju Island, the target city. At the time of achieving the datafor this experiment, 21 DC chargers are in operation. That is,m is 21. For each parameter setting, 10 sets are generated outof 40 destinations. The first experiment measures the effect ofthe number of destinations ranging from 5 to 9 to the traveldistance. Here, the pure tour length without charging, namely,the TSP length, randomly distributes from 100 to 120 *km*. Ascan be known in the figure, the gap from the optimal schemeranging from 9.2 to 11.2 % with m'=1, is remarkably shrunkto the range of 1.6 to 4.5 % with m'=5.

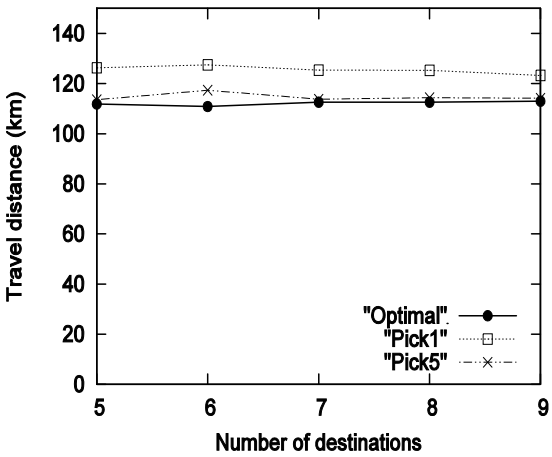


Fig.2. Effect of the number of destinations

Figure 3 plots the effect of the number of picks to the traveldistance. Here again, the TSP length distributes on the intervalfrom 100 to 120 *km*, and the number of destinations is set to7. Even with m' = 2, the travel distance already becomesalmost same as that of the optimal scheme. The difference isonly 1.6 %. Actually, the selected TSP length range createsquite stable results.

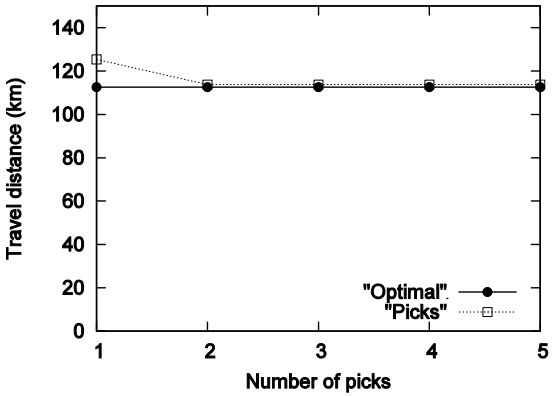


Fig.3. Effect of the number of picks

Finally, Figure 4 shows the travel distance according to theTSP length. For each of 10 *km* intervals from 100 *km*, 10sets are generated. For the case of m'=1, the gap from theoptimal schedule falls to the range from 8.4 to 21.9 %. Thisgap is cut down to the interval from 1.0 to 2.7 %. It can beseen that as the TSP length increase, the proposed schemeworks a little bit poorer, as the average distance between twodestinations gets larger, unless a charger is facilitated in atourist spot. However, this factor has significantly disappearedwith an addition of more candidates.

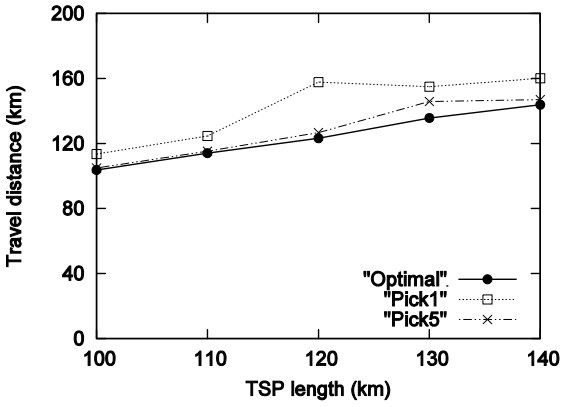


Fig.4. Effect of the TSP length

IV. CONCLUDING REMARKS

In this paper, we have designed a heuristic-based tour-and-chargingscheduler, considering DC chargers which add justone charging for most day tours. By modeling and defining thisproblem as the (n+1) TSP, the heuristic triggers the TSP solverfor a small set of candidate chargers, not the whole ones. Theproposed heuristic gives precedence to those chargers close tothe destination far away from the start point and then picksa limited number of chargers close to the destination. Theperformance measurement result discovers that this schemecan find a suboptimal solution comparable to the optimal onein terms of the tour length, the maximum gap less than 2.7 %.Here, we will further improve the scheme by compensating forthe case the proposed heuristic sometimes misses

the chargerson the exact route of the tour. This computational intelligencewill accelerate the penetration of EVs into our daily lives.

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