Transportation Research Part D 63 (2018) 121–136

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

# Electric vehicle tour planning

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ARTICLE INFO

*Keywords:*
Tour planning
Orienteering problem
Recharging stations
Electric vehicle
Mixed integer programming

ABSTRACT

This study extends the orienteering problem with time windows by considering electric vehicles (EV) with limited range. The model can simulate the change in the battery's state of charge at each point along the routes, and thus can be used to solve the problem of EV tourist trip design with time windows. A land-sea integrated network for Penghu low-carbon islands was tested, and then the optimal green trip designs are obtained using a heuristic method. Some unique properties of the model are also discussed, as well as a number of management or planning implications.

## 1. Introduction

The transport sector accounts for approximately 15% of global greenhouse gas emissions, in large part coming from fossil fuel consumption (OECD, 2010). A number of efforts have been made over several decades to reduce the vehicle miles traveled by road, and thus fossil fuel usage, and to increase engine efficiency, leading to greater mileage per gallon of fuel. One of the most promising approaches to reducing energy use and decreasing the environmental impacts of carbon-based vehicle emissions is the adoption and use of electric vehicles (EV) (Haller et al., 2007; Yeh, 2007; Wang and Lin, 2009). However, the market penetration of EV has remained limited for many years, due to the short driving range, high battery price, and lack of recharging stations, although such issues are now being addressed in a more active manner. In addition, some of the infrastructure needed for EV is now being established. For example, although the range of electric scooters (ES) is still limited to around 30–50 km per charge, the lifecycle of the battery has been lengthened (supported by factors such as three-year use guarantees), and the range can be extended by recharging at stations. EV can thus now play an important role in medium- or short-range travel. For example, Taiwan's government has promoted the use of ES via subsides to replace the use of the conventional two-stroke engine motorcycles. In Penghu, the focus of a five-year low-carbon-islands project, there are currently 3669 ES, and 612 slow-recharging and 20 battery exchange stations (offering partial rental) for use by residents and tourists.

A tourist can now rent an electric-scooter from a rental store sited in the Magong C.B.D., such as from the I-Sun Green-Energy scooter rental firm. However, after he or she rents an ES, the first question raised is where can they travel to using this vehicle? The question is equivalent to the emerging problem of the electric-vehicle tourist tour or trip design. The present problem is quite different from the traditional tourist trip design one, due to the limitation of EV driving range. The previous models should thus be extended to consider the factor of limited range for planning the EV tour or trip. Overall, it is an important issue to design an optimal trip or tour from an origin to a destination for an EV tourist, so that he or she can visit the most points of interests (POIs) with

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https://doi.org/10.1016/j.trd.2018.04.016

consideration of the given locations of battery swapping stations and total travel time (i.e. time budget).

## 2. Literature review

It is often impossible for tourists visiting a city or region for a short time to visit all of the POIs, and so they must select the most important attractions. However, making a feasible plan to visit these in the available time span is often a difficult task (Souffriau et al., 2008, Vansteenwegen et al., 2011, Abbaspour and Samadzadegan, 2011), and this is known as the Tourist Trip Design Problem (TTDP) (Vansteenwegen and Van Oudheusden, 2007), the aim of which is to visit the maximum number of POIs along the feasible routes within a time limit. The simplest model of the TTDP is the orienteering problem (OP), which is based on an outdoor game that is usually played in mountainous or heavily forested areas. In this, individual competitors start at a specified control point, then try to visit as many checkpoints (with a certain score) as possible, and return to the control point within a given time span (Chao et al., 1996, Vansteenwegen et al., 2011). That is, the OP's goal is to maximize the total score collected, and this approach can be easily transformed and applied to solve the problem of tourist trip planning. Moreover, if a single competitor is replaced by a team, then the OP becomes the team orienteering problem (TOP). Golden et al. (1987a, 1987b) prove that the OP is NP-hard, which implies that the exact solution for the OP can only apply to instances with a limited number of nodes, and heuristics will be needed for practical applications.

Tourist tour planning focuses on the selection of POIs and vehicle routing in a given time span. The tour system has four factors (locations (POIs), road network, mode (single or multiple), and time (travel, visiting, and opening hours)) that should be considered in the model. If the factor of the opening hours for each POI is considered, the (T)OP can be extended to (T)OP with time windows ((T)OPTW) (Righini and Salani, 2009, Montemanni and Gambardella, 2009, Vansteenwegen et al., 2009). That is, the TTDP can be modeled as a time window TTDP (TTDPTW). For example, Souffriau et al. (2008) extended their approach for the simplest form of the tourist trip design problem by taking the opening hours of POIs into account, for one day, and examined the feasibility of running the planning algorithm on a mobile device with limited computational resources. The TTDP is solved using a Guided Local Search meta-heuristics. Benchmarks with a size of 95 points were tested and the results show that the approach turns out to be faster and produce solutions of better quality. Vansteenwegen et al. (2011) proposed a fast and effective planning algorithm that provides on-the-fly suggestions for a personal trip that lasts a certain number of days, taking into account the opening hours of attractions and time needed for breaks. Furthermore, if the factors of the travel time between POIs and single or multiple travel modes are considered, the model will become a time-dependent one. For example, Abbaspour and Samadzadegan (2011) addressed the problem of time-dependent tour planning in a complex and large urban area (i.e. the city of San Sebastian with 50 POIs), which may be useful for different groups of people. The key problem here is the determination of chronological sequences of attractions to visit during a specific period using several transportation modes. Garcia et al. (2013) modeled the tourist planning problem, integrating public transportation, as a time-dependent team-orienteering problem with time windows (TDTOPTW) to allow tourists to create personalized tourist routes in real time. Since the travel time between nodes depends on the departure time from the origin POI, the TTDP can be modeled as a time-dependent TOPTW (TDTOPTW). Two algorithms were proposed based on the assumption of periodic service schedules and tested based on the instances of San Sebastian with 50 POIs. The experimental results showed that these approaches are able to obtain routes in real-time. Gavalas et al. (2015) showed that the TDTOPTW can be used to model the route-planning problem for tourists interested in visiting multiple POIs using public transportation. They proposed a set of efficient cluster-based heuristics for TDTOPTW, taking into account time dependency in calculating the travel time between POIs and relaxing the assumption of periodic service schedules. The POIs dataset used in their experiments features 113 sites in the metropolitan area of Athens, Greece.

The range of a transport mode is a critical factor in such models. To the best of our knowledge, the previous models assumed that the focal mode's range can cover the length of the origin-destination (O-D) or the need for recharging is neglected, as the recharging time is much shorter than the time needed for the trips. However, this assumption is obviously no longer appropriate when considering EV, such as ES with a limited range of about 30–50 km per charge. That is, the previous models cannot be used to describe the trip behavior in this context.

Efficient EV routing is an important management issue, and there are various different research streams in EV routing. According to the surveys carried out by Touati-Moungla and Jost (2010) and Schiffer and Walther (2017), there are four main research streams, including energy shortest path problems (ESPPs), electric vehicle routing problem (EVRP), facility location problem (FLP) and electric vehicle location and routing problems (EVLRP).

In effect, these routing problems have four factors: locations (customer, station), road network (directed or undirected), mode (single or multiple), and time (travel, service, and time windows). The factors are similar to those derived from the Tourist Trip Design Problem (TTPP) or Orienteering Problem (OP).

The ESPP and EVRP assume that locations of recharging stations are given as parameters, and aim to make an energy-efficient EV routing plan. Obviously, the problems of the ESPP and EVRP are interdependent. In contrast, the problems of FLP concern station siting while the EVLRP is dedicated to simultaneously determining station siting and EV routing. Our literature review focuses on the problems of ESPP and EVRP. However, a literature survey about recent works and developments with regard to FLP and EVLRP is given in Schiffer and Walther (2017).

Suppose that an EV drives from an origin to a destination along a route or tour on a network with given locations of recharging stations, and a traveler is looking for an optimal energy-efficient route, the specific problem is the ESPP, which is the basic or simplest formulation in EV routing. For, example, Ichimori and Ishii (1981) considered the problem of routing a vehicle with fuel limitations. The optimal route is a shortest path along which a vehicle can pass through a network, visiting some recharging vertices on the way.