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Optimal Pricing for Electric Vehicle Parking Duration at a Charging Station based on a Queueing Model

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Abstract The recent development of Electric Vehicles (EVs) rises many questions in the research community. A Charging Point Operator (CPO), responsible for a given public Charging Station (CS) management aims to maximize her/his profit. The objective of this study is to help a CPO to design her/his pricing policy. The user's reaction to the pricing policy on the decision of joining or not the CS is modeled.

1 Model description

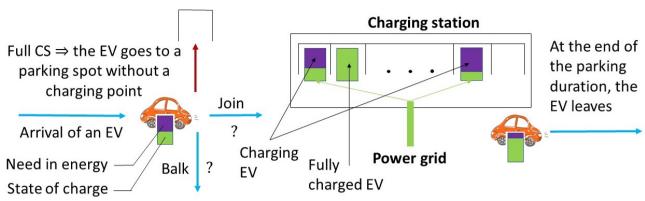
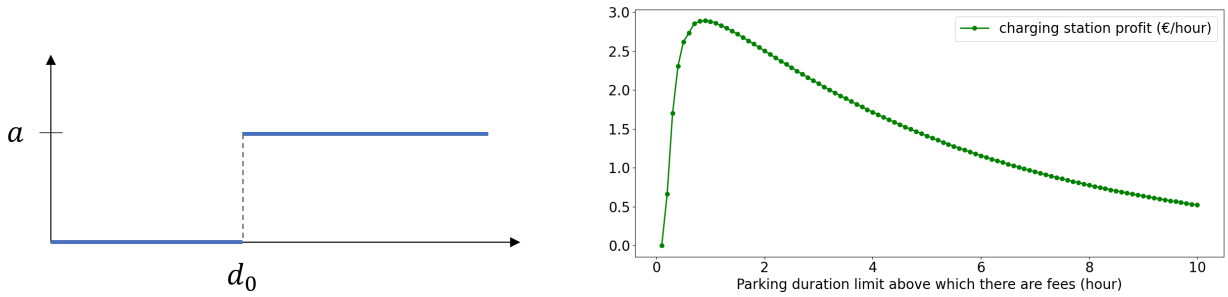


FIG. 1 – Schematic diagram of the considered model

EV characteristics In this model, EV users arrive to an activity center. She/He will go to charge the EV while doing other activities : shopping, restaurant, etc. All EV users arrive at the CS according to the same Poisson process. At the CS, each one of the N_p parking spaces is equipped with one charging spot, delivering a constant power p for charging the EV. The random parking duration of each EV user is independent from the energy required to fully charge the EV battery because the main purpose of the EV user is to do other activities at the site. A parking space can then be occupied by an EV although the EV is not charging because it is fully charged. Given this, at each instant, the number of charging EV may be different from the number of parked EV. In the case of exponential distributions for the need in energy and the parking duration, the number of charging and fully charged EV forms a two-dimensional Markov chain, analyzed in [1].

EV users charging behavior Upon arrival, an EV user observes if the CS is fully occupied, i.e. all parking spaces are occupied by other EVs. If there is an available parking space, the EV user decides whether to join or not the CS, depending on the energy she/he expects to receive and on the pricing policy of the CPO, see Figure 1 for an illustration of the model. The EV user knows the exact energy required to fully charge the battery, but does not know his/her parking duration. The utility is the difference between the energy received and the cost associated with the parking duration. The EV chooses to join the CS if his/her expected utility with respect to the parking duration is positive.



(a) Illustration of the cost function with respect to the parking duration

(b) CPO's profit with respect to the free of charge parking duration limit d_0

FIG. 2 – During peak hours, a CPO aiming at maximizing her/his profit should decrease the parking duration limit above which EV users have to pay.

Optimization problem The CPO wants to find the optimal pricing on the parking duration, in order to maximize the long-run expected profit. The profit depends on the expected number of EV users joining the CS and the expected revenue of the CPO per EV. For a simple beginning, the parking is free of charge if it is sufficiently low, otherwise there is a fixed amount to pay. Figure 2a shows an illustration of the cost function on the parking duration. There is two decision variables : the free of charge parking duration limit as well as the fixed fee if the free of charge parking duration limit is exceeded.

2 Contribution

Pricing mechanisms for public CSs has been widely studied in recent years. However, few papers integrate queuing systems to model the stochastic nature of arrival/departure of EV users at a CS. In [2], a scheduled pricing policy is determined, which depends on the congestion level at the CS, using queueing theory. However, the reaction function to this pricing mechanism is a predetermined parameter. Our previous work [3] integrates the notion of charging decision, through a queueing game [4] between EV users, but does not consider any pricing mechanism. This study provides an charging choice model and an analytical formulation of the profit, which depends on the probability that an arriving EV joins the CS. Uniqueness of the optimal pricing with respect to one variable in order to maximize the CPO's profit is proved. A sensitivity analysis of the solution is also provided.

Références

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