

Evaluate the Customer Behavior in Competitive EV Charging and Parking Services

by

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DEDICATION

This edition of the Master's Thesis by Rui Ma, "SOLVING COMPETITION BETWEEN ELECTRICAL VEHICLE CHARGING AND PARKING FACILITIES WITH GAME THEORY", is dedicated to all the professionals, students and people who are working on or interested in electrical vehicle charging, smart grid, electricity market, game theory and optimization of smart grid.

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LIST OF ABBREVIATIONS AND VARIABLES

$\rho_{i,buyin}(t)$:	i -th deck's electricity buy in price in dollars , varies by time
$\rho_{i,ch}$:	i -th deck's electricity price sells to customers in dollars.
$\rho_{i,p}$:	i -th deck's parking price per hour in dollars.
ρ_i :	Sum of parking and electricity price in dollars.
ρ_{-i} :	Average of sum of parking and electricity price of other decks in dollars.
R_i :	i -th deck's revenue in dollars.
$R_{i,ch}$:	Revenue of charging in dollars.
$R_{i,p}$:	Revenue of parking in dollars.
C_i :	Operational cost in dollars.
$D_i(t)$:	Hourly individual demand of i -th deck in kW·h.
N:	Number of electric vehicles active in the current period (will be in decks). Divided into three groups.
I:	Number of decks in this area.
$a_{i1}(t)$:	Number of active loyalty members getting charged in i -th deck. (By hour)
$a_{i2}(t)$:	Number of Group A's customers parking in i -th deck in time slot t, varies by hour.
$b_i(t)$:	Number of Group B's customers parking in i -th deck during time slot t, various by hour.
$c_i(\rho_i, \rho_{-i}, t)$:	Active customers who come to i^{th} deck (parking time = charging time) but may leave to another deck according to prices, varies by time.
$K_{i,charging}(t)$:	Number of electric vehicles charging in i -th deck in the time period Δt .
$K_{i,parking}(t)$:	Number of electric vehicles parking in i -th deck in time period Δt .
$P_{charging}$:	Charging power in kW.
$P_i(t)$:	Total charging power of i -th deck at time t.
$P_{i,max}(t)$:	Maximum charging power of i -th deck at time t.
$g(\rho_{i,ch}, \rho_{-i,ch})$:	Influence factor of price change on customers' behavior: rate of customers getting charged.
O_i :	Number of outlets in i -th deck.

ABSTRACT

In the last decade, the U.S. government has spurred efforts to boost the utilization of transportation electrification technologies, because of their low-pollution emissions, energy independence, and high fuel economy. An ever-increasing number of electric and plug-in electric vehicles (EVs and PEVs) will radically change the traditional view of the transportation industry, social environment, and business world. Research on grid integration of EVs and PEVs typically addresses topics at the vehicle-grid boundary such as peak load impacts and optimal charging control. While researchers around the world are making significant advances in these areas, there is very little work investigating the customer behavior in competitive EV charging and parking services. On one hand, as a transportation tool and electricity carrier, EV can be charged at any charging facility and at any time, which brings spatial and temporal demand uncertainty to the service providers. On the other hand, the retail electricity price and parking fee may have an impact on customer behavior, eventually leading to a change in the expected profits of the service providers. In this thesis, the dynamic interactions between service providers and customers are studied and modeled using game theory. In the abovementioned competition, the players decide their own strategies (i.e., retail electricity price, parking fee, and rebate) while considering a variety of physical constraints such as transformer capacity. The customer segmentation is also taken into consideration. More specifically, the competitive market is studied using a non-cooperative Bertrand game. Case studies demonstrate the accuracy, and effectiveness of the proposed solution algorithms

Chapter 1

Introduction

1.1. Background

Electric Vehicles are growing in popularity as a solution of higher power efficient and low emission alternative to the fuel based conventional vehicles driven by internal combustion engines[1]. Driven by the consuming of natural fossil fuel reserves and rising petrol costs, governments of various countries have regulated policy to adopt more sustainable technologies such as electric vehicles[2], thus Original Equipment Manufacturers such as Ford and GM have already begun to roll out plug-in electric vehicles from their product lines with many more companies promising to expand their business into the electric vehicle market. Higher penetration of electric vehicle in the market will bring both challenges and opportunities to the existing power grid system. Besides the challenges it will bring to the demand side management system, the potential contribution of EVs to the peak-valley shifting also cannot be ignored[5]. EV charging and parking facilities, as an interface between utility companies and EV owners, will contribute to both of the aspects stated above.

The relationship between EVs and EV charging/parking decks are similar conventional vehicles and gas stations. A paradigm shift is shown in Fig. 1 as well as the comparison between these two features. Considering the EVs need to be charged and as more and more charging facilities are installed in parking decks, these decks could be the interface between the EVs and the utility grid and could be seen as agents of the utility company used to control the charging scenarios. As a result of increase of EV number and development of EVs, it could be foreseen that there would also be an explosive increase in EV charging/parking deck's

number0

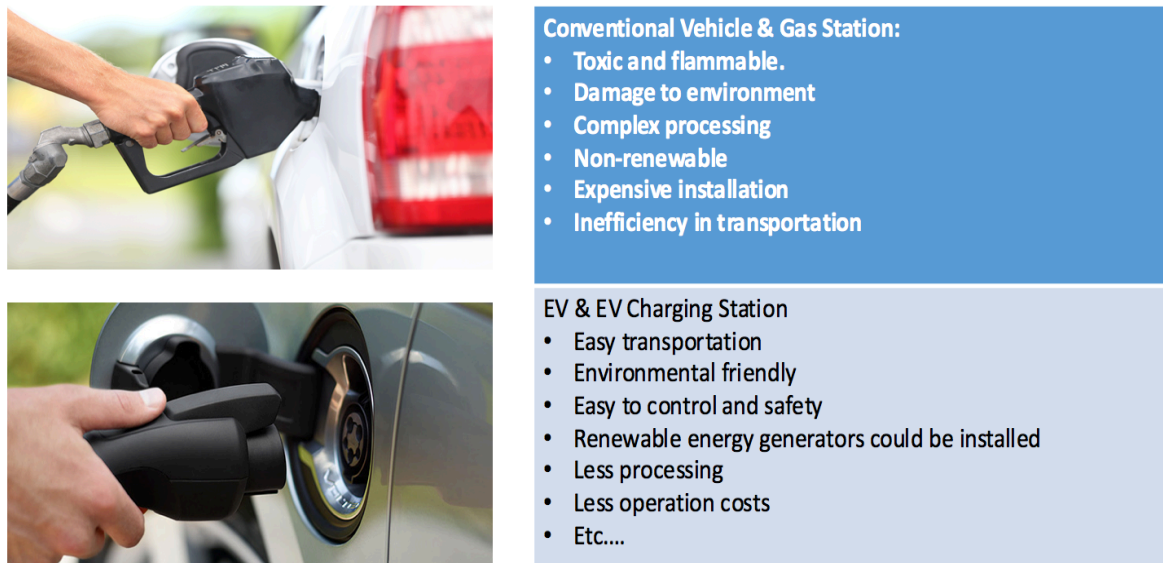


Fig. 1 A parading shift: Conventional vehicle and gas station VS Electric vehicle and charging station

Though there are many things that EV charging facilities have in common with the gas station, differences between the behavior of EV customers and conventional vehicle owners can't be ignored, studies about competition among gas stations may not be applicable to EV charging/parking decks. Herein, we consider the game between decks that will deal with customers of different response to the price changes0.

1.2. Objective and System framework

When there are couple of decks in the same local area under different ownerships, customers are given more choices of charging and parking their vehicles, therefore decks tend to compete between each other to maximize their own revenue. Decks can make decision on their electricity price and parking fee to fulfill different financial strategy. For instance, decks will apply Low-price strategy when a higher market share is desired and though price margin is low, net income would still be high because of the large number of sales0. In competition among decks, price strategy of decks' will have influence on customers' behavior. And as a

feedback, customers' response to prices of decks will have an impact on decks revenue. No matter what kind of financial strategy is applied to a deck, the only destination of a deck would be find the optimized price strategy that can make the highest profit volume. When different financial strategies are applied to different decks, the competition among decks will become complex and sophisticate. The objective of this thesis work is to help EV charging and parking facilities finding the optimized financial strategy (electricity selling price and parking fee) an maximize their revenue. Studies of the related field will also have a positive influence on the development and universalization of EV charging and parking facilities and thus help generalizing EVs and benefit the utility companies as well.

While analyzing the proposed structure, we divided the structure into three different levels. The higher level energy prosumers, second level energy trading agents and customers (EV owners) and each layer will be discussed as in the follow sections. The proposed structure among utility company, EV owners and the EV charging and parking facilities is shown below in Fig. 2. The Utility is a representation of higher level energy prosumers and suppliers while the Decks represents the second level energy trading agents (EV charging and parking facilities) between the higher level and customers. The higher level energy supplier can decide the

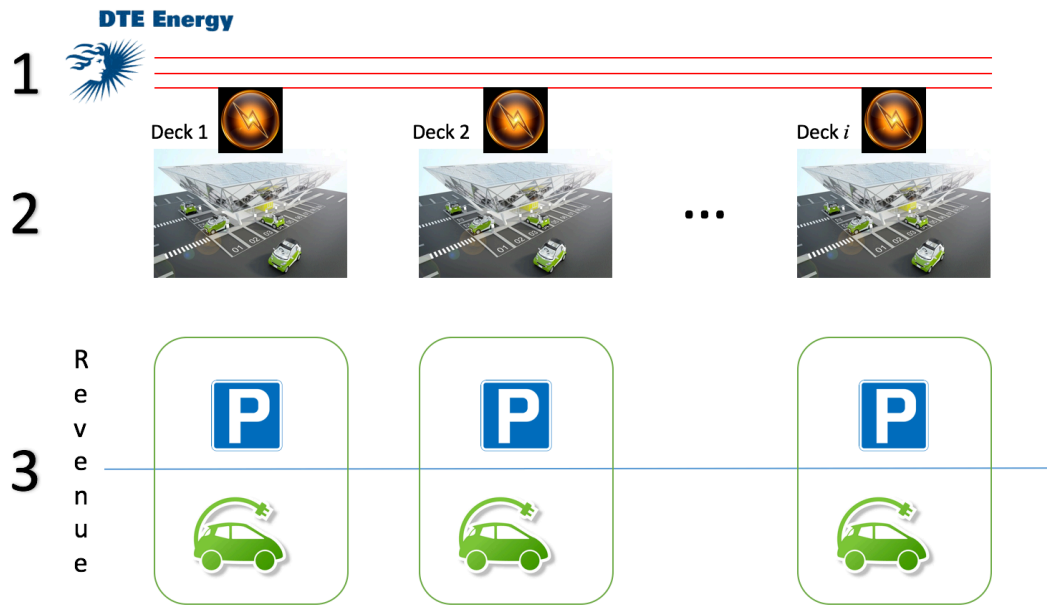


Fig.2 Proposed System Structure

electricity selling price to the second level agents while the agents will choose their electricity selling price to the customers and their parking fees.

1.2.1 Higher Level Energy Prosumers

The higher level energy prosumers are responsible for generating electricity using various methods such as PV cells (photovoltaic cells), wind turbine and conventional electricity generator which based on fossil fuel⁰. It is the highest energy level of our proposed system. It also has the responsibility of setting the electricity sell price to the second level energy trading agents to have a basic control of the electricity market⁰⁰. The member of this level could be utility companies such as Virginia Electric & Power, DTE Energy and Public Service Elec & Gas.

1.2.2 Second Level Energy Trading Agent

Second level energy trading agents consists of EV charging and parking facilities whose responsibility is to sell electricity to EV owners and provide parking services⁰. They are capable of setting electricity selling prices to EV owners as well as parking fees. Some of these agents could install renewable energy generators as a method to reduce their costs since they

can buy less energy from the higher level prosumers. Their electricity selling price as well as their parking fee will response to electricity price change and the change of customer behaviors. Though their destination is to make profits for their own, they are acting as the interface between utility companies as customers.

1.2.3 Customer Level

The customer level is made of EV owners. They will response to electricity selling price and parking fee change of EV charging and parking facilities and decide where to park and charge their vehicles⁰. Customers have different preferences and behavior models, as a matter of regulating in the thesis and getting the simulation results, the customer behavior (their response to price changes of agents) needs to be classified and quantified.

1.3. Organization

The Introduction about the whole thesis was presented in chapter 1. In chapter 2, contribution of this thesis, system specifications as well as the theories and algorithms applied will be presented. In chapter 3, the mathematical model, the case study simulation results as well as the analysis will be demonstrated. The applied algorithms will also be investigated. A conclusion and future work will be discussed in chapter 4.

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Chapter 2

Problem statement

2.1. Contributions

Most of existing works regarding EVs and utility grid are about power allocation and peak shifting etc. A game theoretical way of charging EVs in a deck is proposed in [1]. Different charging scenarios and charging strategies are mentioned in 0. Distributed charging control of EVs is introduced in 0. Energy trading between Smart Grid and PEV groups is studied in 0. An intelligent PEV charging method that significantly reduces power system cost while maintaining reliability is proposed in 0. An optimized model of peak valley shifting with EV charging is presented in 0.

The main contribution of this paper is listed below:

1. We study the competition from the angle of one EV charging/parking decks and propose a framework that can find optimized price strategies for decks at the Nash Equilibrium point.
2. We study the price competition among decks with game theory. We specify the properties of the problem and solve it with an appropriate game theory model.
3. We realize that customers, according to their reactions to price changes, can be divided into three groups. Then we quantify the possibility of customers' response by different groups so that we can forecast customers' behaviors in simulation.

2.2. System Specification

In the system we assumed, all decks are capable of making their own price decision of both electricity price and parking fee. Being an independent and selfish entity, a deck's goal is to maximize its own revenue and since in the system each deck has similar operational cost, decks' profits grow as their revenue grow.

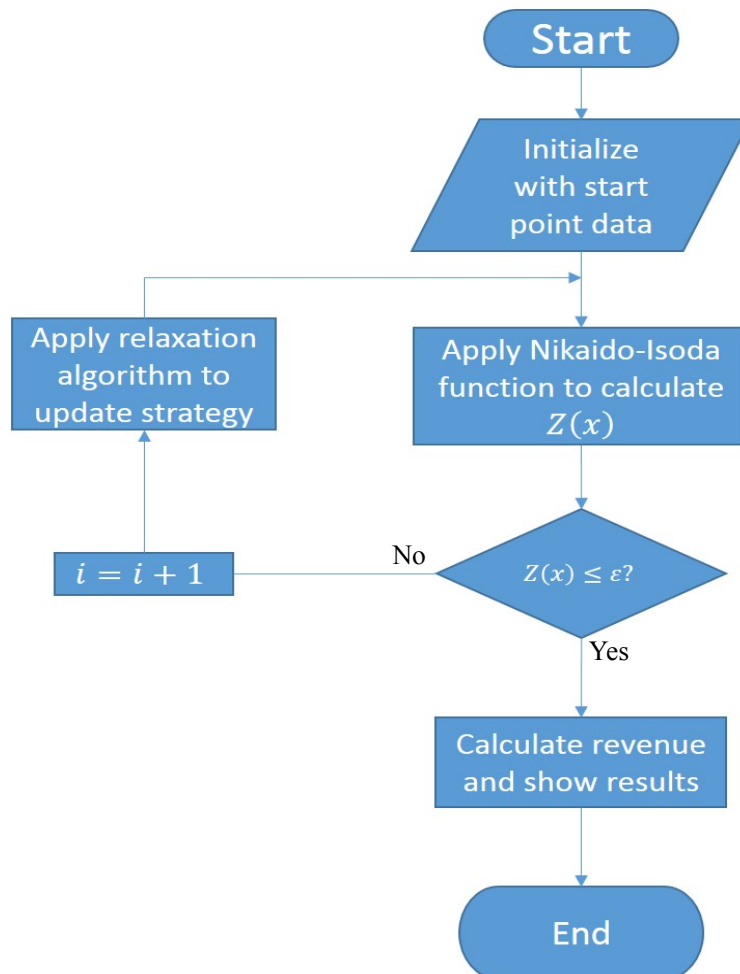


Fig. 3 Flowchart of the proposed game-theoretic algorithm

There are 6 decks of 6 different owners in the basic system. We focus on the day-ahead operation of EV decks, so we assume the decks can choose to alter their electricity price and parking fee every hour, that is saying $\Delta t = 1 \text{ hour}$. **Fig. 3** shows the flow chart of how our system helps a deck to make price decision using game-theoretic algorithm.

In this system, Nikaido-Isoda function and relaxation algorithm are applied to find the Nash Equilibrium point. Firstly, we have the same start point for each deck. In the simulation, the jump out condition ε is set to be 10^{-8} , that is saying, when the difference between last decision and the next step decision is smaller than this value, the system will jump out of the loop and give out the value of this iteration as the final result, otherwise, the system will go on updating the price strategy by applying the above algorithm to the process until the terminal condition is satisfied. In the relaxation algorithm applied to update simulation results, the ratio is set to 0.5 for the simplicity of calculation. Finally, the decision for the next day's price strategy and revenue for each deck at the Nash Equilibrium point is shown.

In the following case studies of the next chapter, the convergence of a "6 decks owned by 6 owners" system is performed. Further in the second case study, buy-in strategy and grouping strategy are also applied to the system as another way to improve decks' revenue. The impact of different customer groups, as a factor of great influence to the game, is also studied in the following case study. The influence is studied by changing the customer groups' volume while keeping the total customer number of each deck unchanged, which is, changing the weighting of different groups for each deck.

All simulations were run on an 6th Generation Intel® Core™ i7-6700HQ Processor (6M Cache, up to 3.50 GHz) computer with an 8.00 GB memory. Averagely it takes 14.83 seconds to converge.

2.3. Theory and Applied Algorithm

2.3.1 Game Theory

In this section, the concept of game theory and the algorithm needed to solve the presented problem will be introduced.

Assuming there are $i=1, 2, 3 \dots I$ players participating the game. Then a vector x_i is used to present the strategy taken by the i -th player. If all the players act together, we can have a collective strategy set $x = \{x_1, x_2, \dots, x_I\}$, we use φ_i to represent the payoff function of i -th player, which indicates the profit that i -th player can gain by taking its own strategy given a strategy space of others. In this paper, EV charging decks are considered players. There fore ρ_i denotes the price strategy (both electricity charge and parking fee) of i -th deck. $(y_i|x)$ denotes the element $(x_1, \dots, x_{i-1}, y_i, x_{i+1}, \dots, x_I)$. This indicates that the i -th player take the action of y_i while the others take the action set of $(x_1, \dots, x_{i-1}, x_{i+1}, \dots, x_I)$. The Nash equilibrium point is defined as:

$$x^* = (x_1^*, \dots, x_I^*), \forall i \quad (1)$$

$$\varphi_i(x^*) = \max_{(X_i|x^*) \in \rho} \varphi_i(X_i|x) \quad (2)$$

Where X_i is the strategy space of the i -th player, in this paper, which is the price sets for the i -th EV charging deck. The collective strategy set is: $X = X_1 \times X_2 \times \dots \times X_I$

Therefore, if there exist a Nash equilibrium point, then, at that point, all the players subject to the following formula:

$$\varphi_i(x_i^*|x^*) \geq \varphi_i(x_i|x^*), \forall i \quad (3)$$

Here, (3) shows that all the players cannot improve their payoff by unilaterally changing its own strategy while the strategies of other players are fixed.

2.3.2 Nikaido-Isoda Function

In 0, the Nikaido-Isoda function which can transform the Nash equilibrium point searching problem to an optimization problem is introduced.

Nikaido-Isoda function is defined as:

$$\Psi(x, y) = \sum_{i=1}^I [\varphi_i(y_i|x) - \varphi_i(x)] \quad (4)$$

The right side of (4) represents the improvements in payoff that the i -th player will receive when the player changes the strategy from x_i to y_i while other players stick to the strategy set x . Thus, this function represents the sum of the improvements for all the players in regards to the payoff functions. x^* can be considered as the Nash normalized equilibrium point if:

$$\text{Max}_{(x^*,y) \in X} \Psi(x^*, y) = 0 \quad (5)$$

When (5) is satisfied, none of the decks can improve their revenue by unilaterally changing its price while the strategies of other decks remain steady. Under certain concavity conditions, a Nash equilibrium point will be reached. In this paper, since the $g(\rho_{i,ch}, \rho_{-i,ch})$ is a convex concave function, we can solve the Nash equilibrium problem by represent it by the following optimization problem:

$$Z(x) = \text{argmax}_{y \in X} \Psi(x, y), Z(x) \in X \quad (6)$$

The *argmax* represents the argument of maximum.

2.3.3 Relaxation Algorithm

The relaxation algorithm is used to update the results of the optimal response function at every iteration step before it converges to the Nash equilibrium point. The initial estimate is set as x^0 , which is a null vector. The relaxation algorithm could be represented as below:

$$x^{k+1} = (1 - \theta_k)x^k + \theta_k Z(x^k), 0 < \theta_k < 1 \quad (7)$$

Where k is the iteration number, θ_k is the weighting term at the iteration k . The relaxation algorithm ensures the convergence under certain concavity conditions. For sake of simplicity, the value of θ_k is set to be 0.5 and this satisfies the convergence conditions at the same time. Also the complete and detailed proof regarding the convergence of relaxation algorithm can be found in [10] of which our targeted problem meets all the sufficient conditions. The stopping condition is set as below:

$$\text{Max}_{(x^k,y) \in X} \Psi(x^k, y) < \varepsilon \quad (8)$$

where ε is a small value used to control the convergence rate.

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Chapter 3

Mathematical Model

3.1. Problem Formulation

In this paper, we consider a model of a local area of few EV charging/parking decks. These decks are capable of electricity trading with customers and utility company and providing parking services to customers. Being individual charging and parking facilities for EVs, their goals are to maximize their own revenue by changing their price variables for electricity and parking service[1]. Customers in this area can be divided into different groups according to their preferences for decks. Characters of decks that might have an influence on customers' preferences would mainly be price, location and other customized character like service attitude and relationship with local customers but not limited[4].

1. We have same initial electricity and parking price for all decks.
2. We start iteration steps in which Nikaido-Isoda function and relaxation algorithm are applied.
3. We run iteration, help decks to update their price strategy until termination condition is satisfied.
4. Finally, there will be a balanced point that no deck could improve its own revenue while others remain the same price strategy.

The objective of the i -th EV charging/parking deck is to maximize its own revenue, which consist of two individual parts: charging and parking. The objective function of i -th deck would be

$$R_i = R_{ci} + R_{pi} - C_i \quad (9)$$

Where R_i represents the total revenue of i -th deck, R_{ci} and R_{pi} represents the revenue for i -th deck from charging and parking portion. C_i represents the daily operational cost of i -th deck.

1. Charging

Customers are divided into three groups for all decks accordingly by their charging/parking behaviors. **Table 1** shows the groups of customers, gives a description and example of each group.

Table 1 Customer Groups

Group of customers	Description	Charging: price sensitive	Parking: price sensitive	Examples
A	Consist of loyalty customers who will have their EV charged at the same deck for same time duration every day.	No	No	Customers work/live in located area care more about characteristics like renewable energy other than prices.
B	Consists of customers who will park their EV at same deck every day but may change their charging time according to the prices.	Yes	No	Customers work/live in located area, cares about electricity prices but unwilling to

				go to another deck due to location variance.
C	Consists of customers that will only go to decks to charge their EVs and leave afterwards. Group C's customer's choice (which deck to go to) is relevant to i -th deck's price ρ_i and average price of other decks ρ_{-i} .	Yes	Yes	Park-to-shop customers or customers stopping by for visiting.

Therefore the customer number by hour of each deck at time t $K_{i,charging}(t)$ is:

$$K_{i,charging}(t) = a_{i1}(t) + g(\rho_{i,ch}, \rho_{-i,ch}) \times b_i(t) + c_i(\rho_i, \rho_{-i}, t) \quad (10)$$

In the formulation above, $a_{i1}(t)$ is the number of EVs belongs to Group A getting charged in i -th deck in time slot t , $b_i(t)$ is the number of EVs belongs to Group B parking in i -th deck in time slot t , $c_i(\rho_i, \rho_{-i}, t)$ is the number of EVs belongs to Group C parking in i -th deck in time slot t . These numbers could be known from forecast model. The $g(\rho_{i,ch}, \rho_{-i,ch})$ in (10) is the influence factor of price change on customers' behavior, which is a non-increasing function, when the price goes up some customers will cut down their charging time to save money, $\rho_{i,ch}$ represents the electricity sell price of i -th deck to its customers, $\rho_{-i,ch}$ represents the average price of all other decks.

For all the players, we define $\rho_{i,ch} \in [\rho_{1,ch}, \dots, \rho_{I,ch}]$. We assume that $g(\rho_{i,ch}, \rho_{-i,ch})$ for all players satisfy the following properties:

Property 1: Nonincreasing as $\rho_{i,ch}$ increases. This means when price of one deck goes up

while other decks not changing their prices, the customers trend not to charge their vehicle at this deck.

$$\frac{\partial g(\rho_{i,ch}, \rho_{-i,ch})}{\partial \rho_{i,ch}} \leq 0 \quad (11)$$

Property 2: Nondecreasing as $\rho_{-i,ch}$ increases. This means when the price of other decks goes up while our deck's price keeps constant, the customers of one deck will be more likely to charge their vehicle at this deck.

$$\frac{\partial g(\rho_{i,ch}, \rho_{-i,ch})}{\partial \rho_{-i,ch}} \geq 0 \quad (12)$$

But as the price goes up, the increase of price trend to have less influence on the change of customer number choose to charge their vehicle in our deck. Thus:

$$\frac{\partial^2 g(\rho_{i,ch}, \rho_{-i,ch})}{\partial \rho_{-i,ch}^2} \leq 0 \quad (13)$$

As stated above, we consider the utility of $g(\rho_{i,ch}, \rho_{-i,ch})$:

$$g(\rho_{i,ch}, \rho_{-i,ch}) = -\rho_{i,ch}^2 + \alpha \rho_{-i,ch} - \frac{\alpha}{4} \rho_{-i,ch}^2 \quad (14)$$

Where α is a positive integer. Same properties also apply to $c_i(\rho_i, \rho_{-i}, t)$.

$$c_i(\rho_i, \rho_{-i}) = \eta \left(-0.05 \rho_i^2 + \alpha \rho_{-i} - \frac{\alpha}{4} \rho_{-i}^2 \right) \quad (15)$$

Accordingly, the demand of power $D_i(t)$, in kw for each deck would be:

$$D_i(t) = K_{i,charging}(t) \times P_{charging} \quad (16)$$

While $P_{charging}$ is the charging power.

The revenue of charging for i -th deck in dollar:

$$R_{ci} = \sum_{t=1}^{24} (\rho_{i,ch} - \rho_{i,buyin}(t)) \times D_i(t) \quad (17)$$

While $\rho_{i,buyin}(t)$ represents the electricity buy in price of i th deck, varies by time, $D_i(t)$

denotes the power demand in kw.

2. Parking

Formulas given above are for the EV charging revenue, and here come the ones for parking:

$$R_{pi} = \sum_{t=1}^{24} K_{i,parking} \times \rho_{i,parking} \quad (18)$$

In which $K_{i,parking}$ is the number of electric vehicles parking in i -th deck in time period Δt :

$$K_{i,parking} = c_i(\rho_i, \rho_{-i}, t) + a_{i2}(t) + b_i(t) \quad (19)$$

3.2. Case Studied

3.2.1 Case Study One: *Check of Convergence.*

In this case, we calculate the day-ahead value of each deck's electricity selling price and parking fee for the next day. We assume that 6 decks are owned by 6 different owners and they compete with each other. The destination of all players (6 decks) is to maximize their own revenue under a set of constraints. Though total customer number for the whole day is similar, time distributed number and group weighting various from deck to deck, which lead to different price strategy of each deck.

3.2.2 Case Study Two: *Evaluate Customer Influences on decks' strategies*

Since all revenue of decks we assumed come from customers and the goal of the proposed framework is to find maximized revenue for decks, customer would be a big factor we need to

study. In this case study, the influence of three groups of customers on the decks' revenue is shown to provide decks with more information in decision making.

In order to study the customers' weighting to different decks of various price strategies, a series of group volume changes are made as below.

We reduced the customer number of each group of one deck (deck 6) to zero and see what influence it has on the other decks price strategy and revenue.

3.2.3 Case Study Three: *Evaluate Customer Influences on decks' revenue*

Then we reduce Group C customers' number of all decks by 100 and add it to their Group A and Group B customers to see the dependence of each deck on different customer groups.

Apparently there could be more combinations in order to study more of the aspects of the influences, but we made these changes intendedly to study the relationship between decks' revenue and some of the characteristics of customers from different groups such as mobility and charging, parking flexibility. Some changes to the customer groups may have more impacts on the market some may not, in order to show if there is going to be a change of the decks' revenue, some studies are made to be a little bit aggressive unless influences in revenue are big enough to show the impact.

3.3. Analysis

3.3.1 Check of Convergence.

Fig. 4 (a) shows the convergence of electricity price of all decks and **Fig. 4 (b)** shows the convergence of parking fee of all decks. All decks share same starting point for both electricity price and parking fee, differences start to show after first iteration as different price strategies are chosen by different decks. As shown in both figures, the two price strategies of each deck are converging to an equilibrium condition after several iterations. After 27 steps the stopping condition is satisfied and the system reaches a Nash Equilibrium point, at which no deck will be able to improve their revenue by changing their price strategy unilaterally.

By assigning value of customer numbers to function stated in previous section, the total revenue of each deck is found as shown in Fig. 4 (c). As the weighting of different customer group varies from deck to deck and other differences in coefficients, the price strategy of each deck varies too. For deck 1, deck 3 and deck 5, higher parking fee strategy is chosen and for

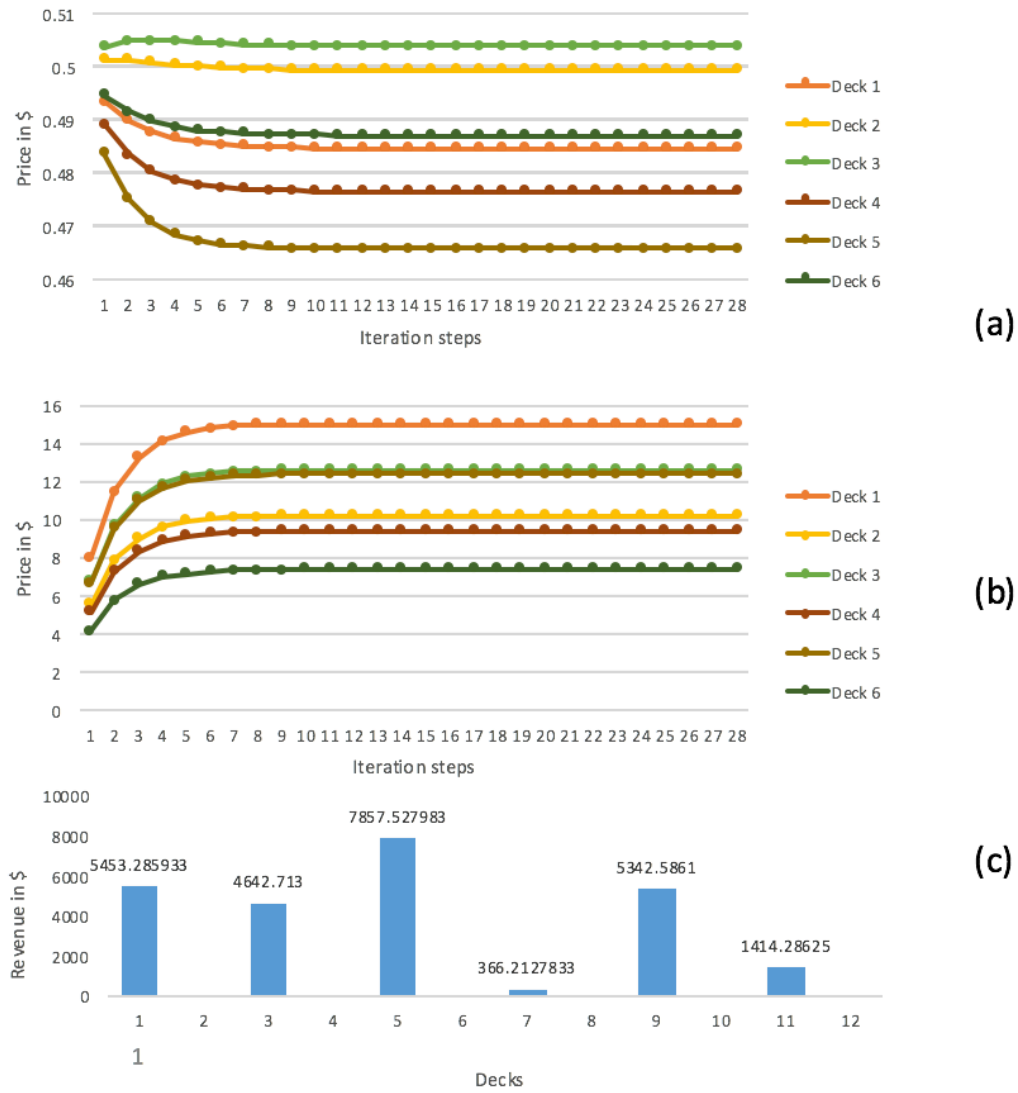


Fig. 4 The convergence of parking fee of all deck

deck 2 and deck 3 higher electricity strategy is chosen to maximize their revenue. Deck 4 and deck 6 applied low price strategy to both charging aspect and parking aspect so that the total revenue is relatively low compared to other decks, for example, deck 3.

3.3.2 Evaluate Customer Influences on strategies

Fig. 5 to Fig. 7 shows the after-change decks' price strategies and decks' revenues. More specifically, (a), (b), (c) in Fig. 5 shows the electricity price, parking fee and total revenue after

deck 6's Group C customer number reduced to zero, (a), (b), (c) in **Fig. 6** shows the electricity price, parking fee and total revenue after deck 6's Group B customer number reduced to zero and (a), (b), (c) in **Fig. 7** shows the electricity price, parking fee and total revenue after deck 6's Group A customer number reduced to zero.

From the comparison of **Fig. 5-Fig. 7** and **Fig. 4 (a) (b) (c)**, we can easily draw the conclusion that Group C customer's response to decks' price influence the system the most, both to the other decks' price strategy and revenue. Since the customers' response to price for this deck would be of less flexibility, deck 6 trend to have higher price to maintain maximized revenue. And for Group A and B customers, they obtain lower level flexibility, so when changing the number of there customers, it will only have little influence on the other decks' price strategy, thus the influence on the revenue for other deck would also be minor. But since Group B customers obtain a great volume of customer number, losing Group B customer will dramatically do harm to decks' total revenue.

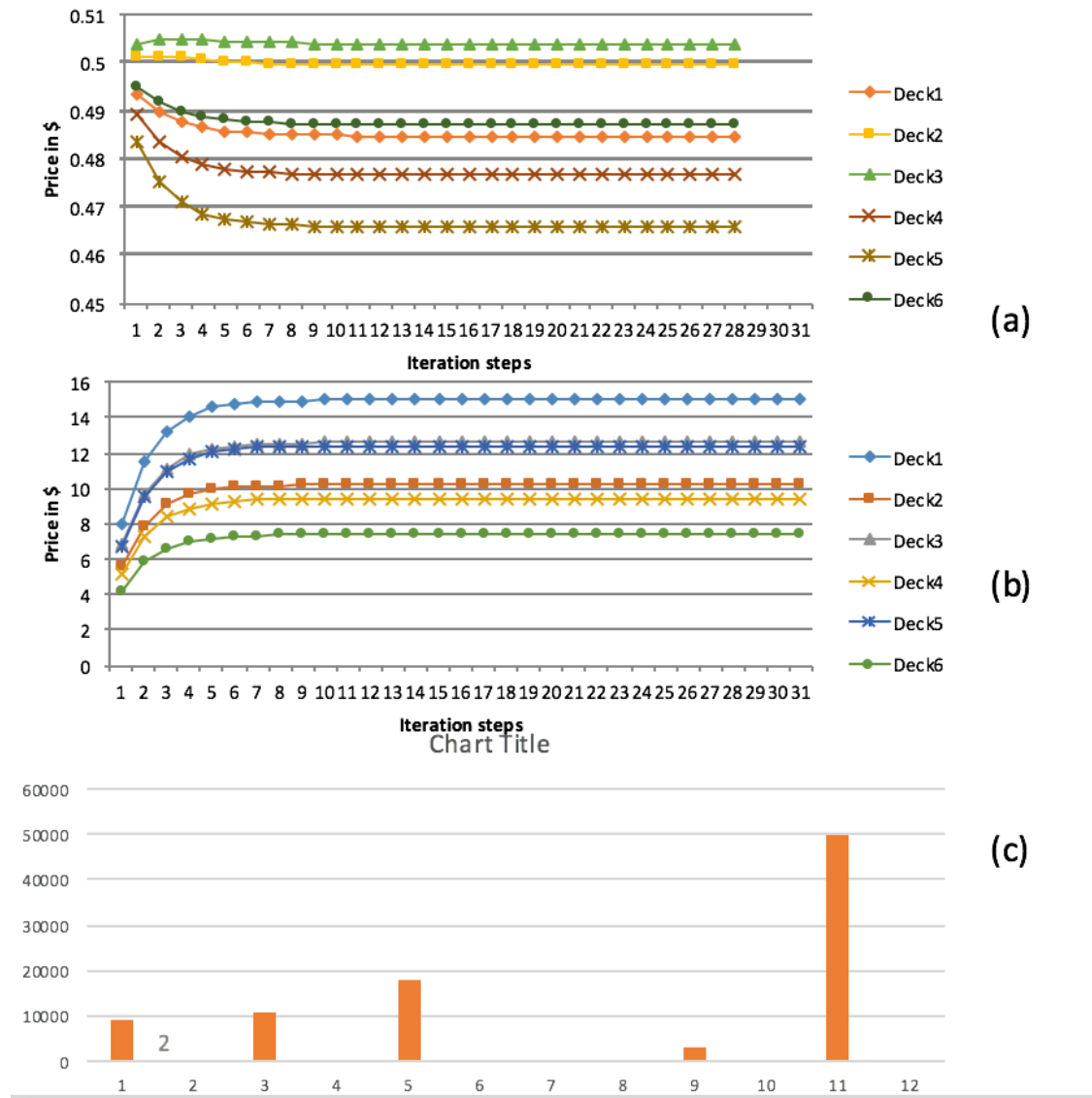


Fig. 5 The electricity price, parking fee and total revenue after deck 6's Group C customer number reduced to zero

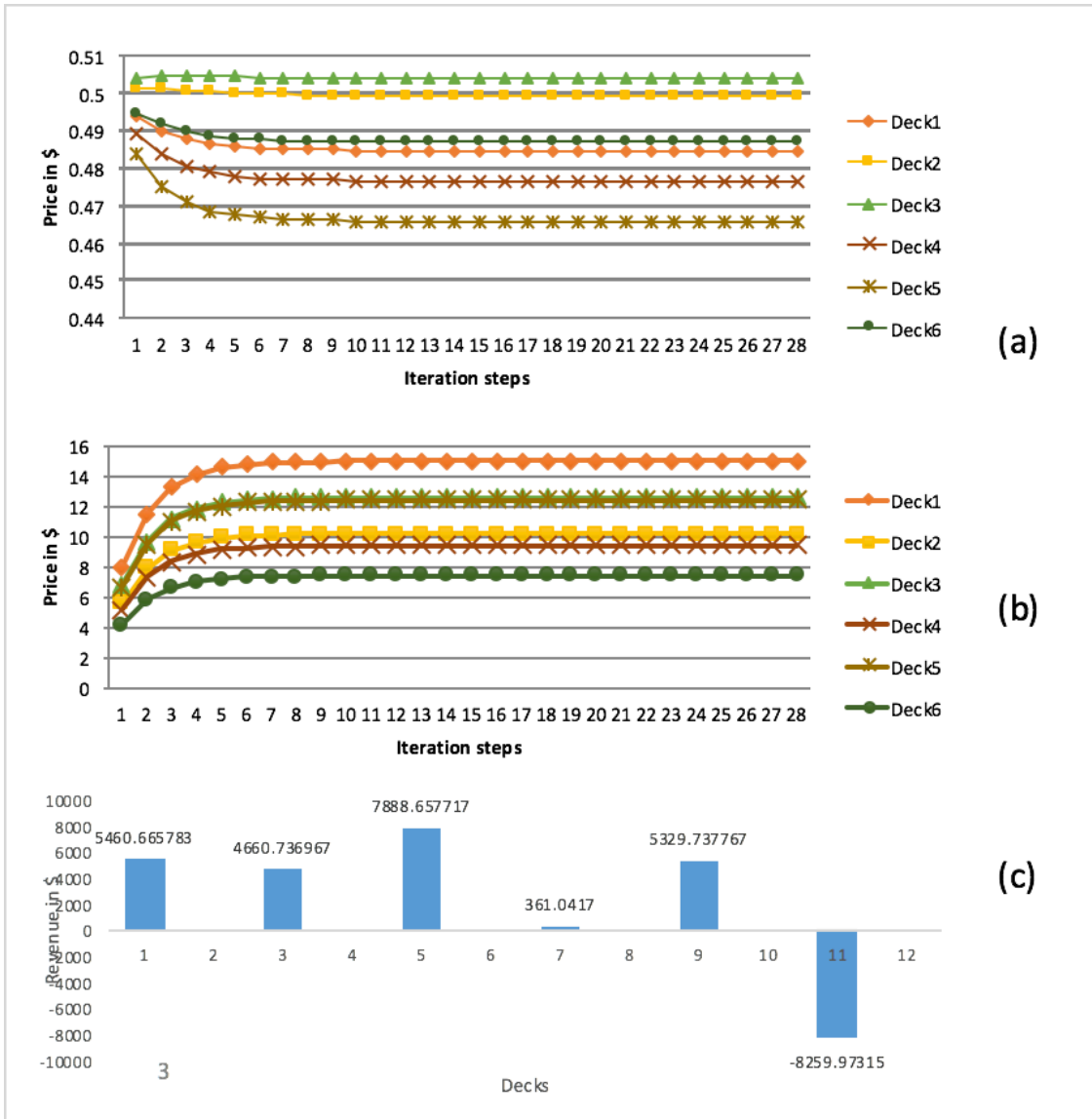


Fig. 6 The electricity price, parking fee and total revenue after deck 6's Group B customer number reduced to zero

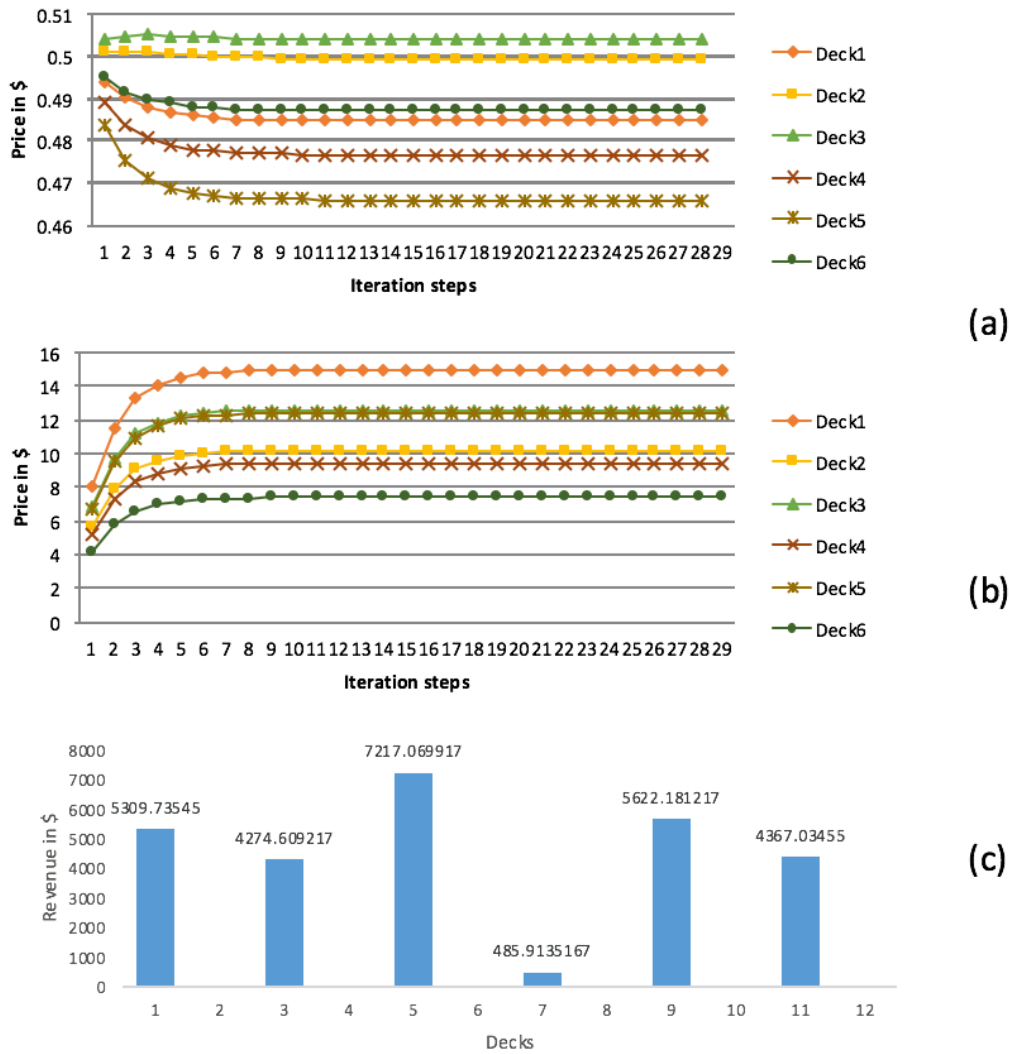


Fig. 7 The electricity price, parking fee and total revenue after deck 6's Group A customer number reduced to zero

3.3.3 Evaluate Customer Influences on revenues

When we add the 100 customers reduced from Group C to Group B customers, all decks trend to gain more profit by different number, but deck 1, 2, 3, 6 will gain less profit compared to adding the number to Group A customers, which is shown in **Fig. 8** (a), (b), (c). In (a), (b) and (c) shown in **Fig. 9**, we add the reduced 100 customers from Group C to Group A customers. From the figure it can be seen that all decks price strategy trend to get higher when compared to the first case study. The reason might be when there is less Group C customers, decks can have higher price for electricity and parking without taking the risk of losing big amount of customers. As for the revenue, revenue of deck 1, 2, 3, 6 increased because of higher electricity

price as well as more parking services are needed. Deck 4, 5 will lose some profit when compared to the first case study.

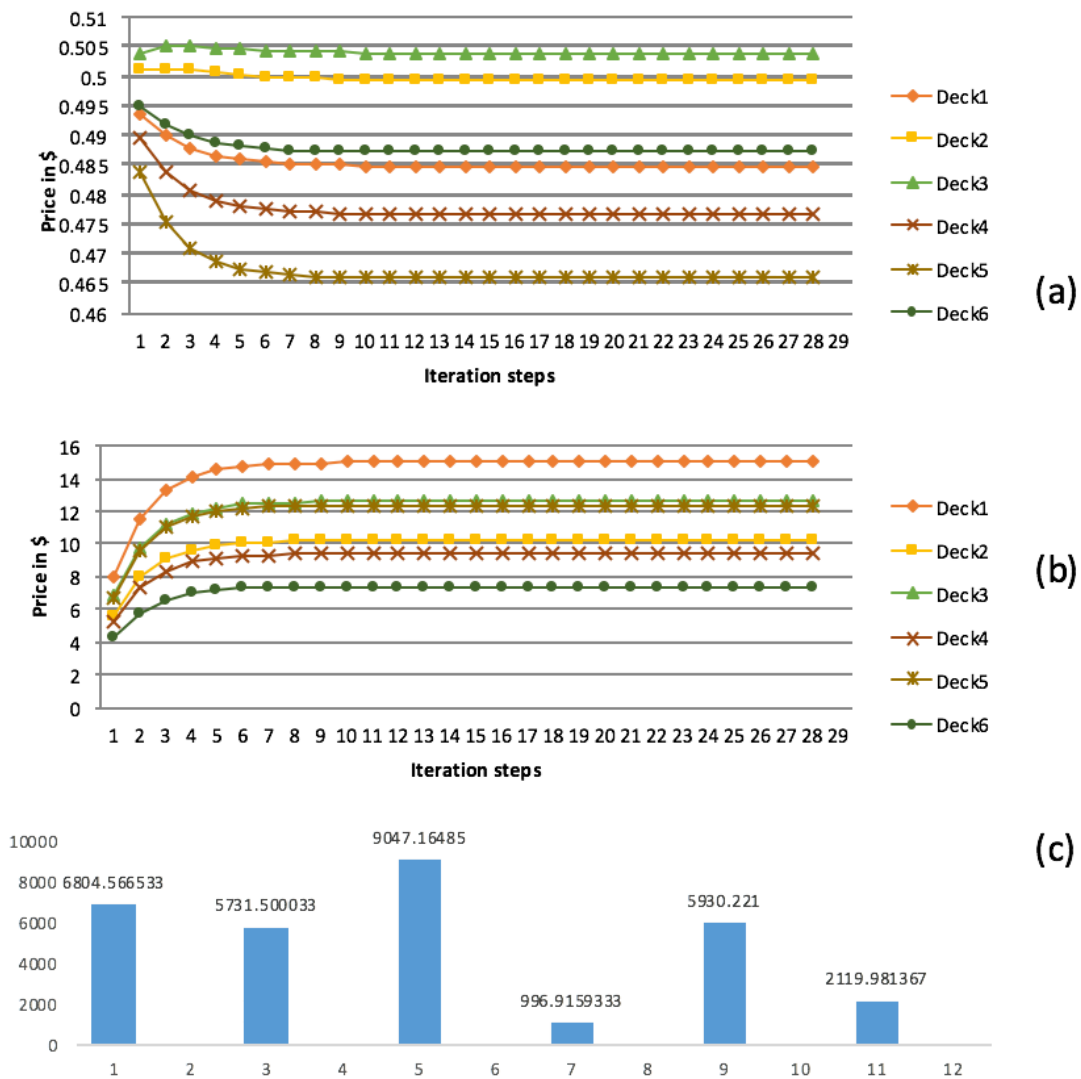


Fig. 8 The electricity price, parking fee and total revenue after all decks' Group C customer number reduced 100 and added to Group B

Overall, we draw the general conclusion that the impact customer behavior has on decks' strategies and revenue proportion grows with the flexibility when customer choosing a deck to charge and park their vehicle, and the impact customer behavior has on decks' revenue absolute value grows with the inflexibility when customers are choosing a deck to charge and park their EVs.

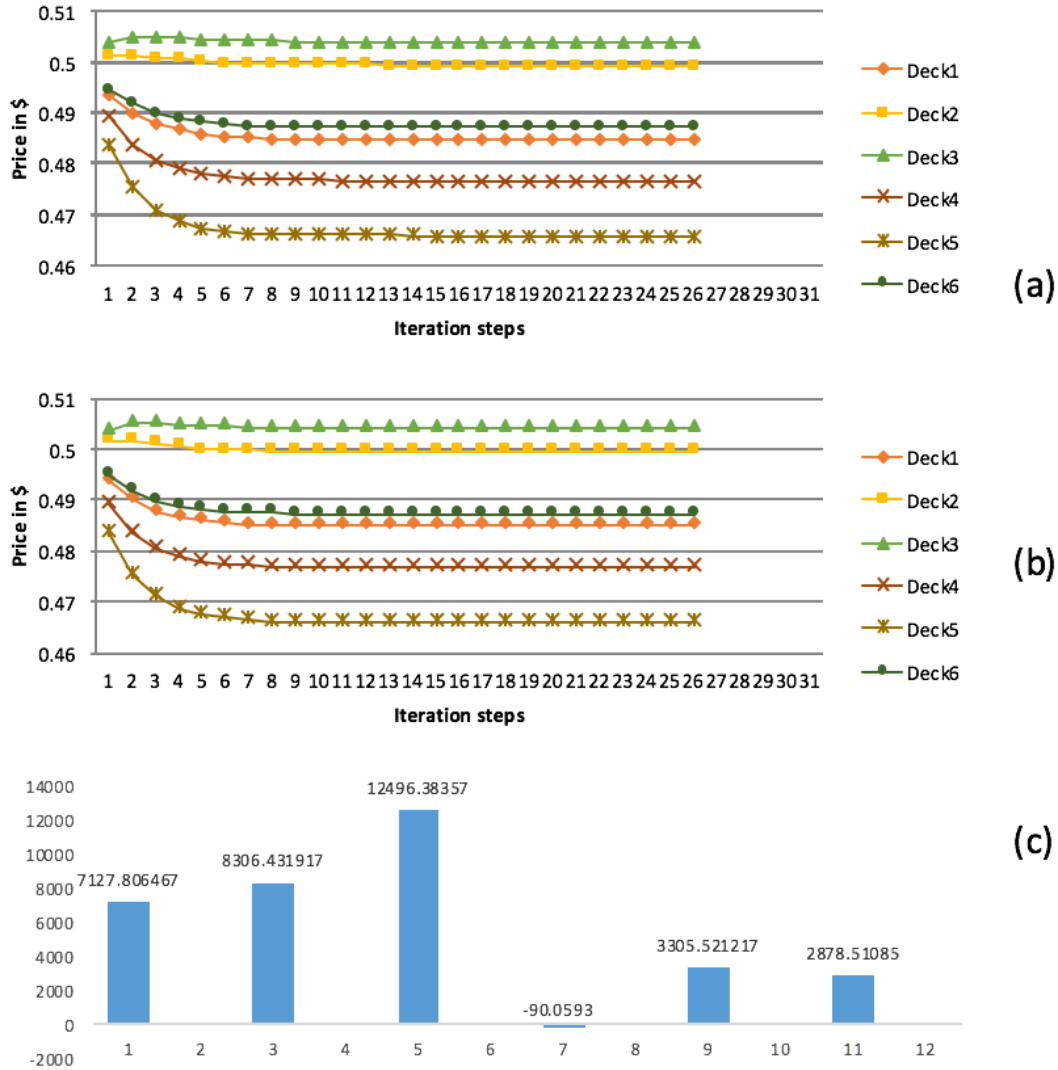


Fig. 9 The electricity price, parking fee and total revenue after all decks' Group C customer number reduced 100 and added to Group A

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Chapter 4

Conclusion and future work

In the upcoming future, it can be foreseen that Electric Vehicles are about to take more responsibilities in transportation system and therefore its contribution in improving utility grid will be more significant. Researches in the EVs as well as EV charging/parking facilities will undoubtedly help improve the development of the not so well constructed EV market.

In order to keep up with the evolution undergoing in the field of electric vehicle and power grid, relationships of different game players would need to be modified or even redefined. With the awareness of the changes and the proper definition of roles of different players in the market, we can boost up the steps as well as benefit more from the evolution.

In this paper, we modified the competition between decks into mathematical model. Then we summarized it, transformed it into optimization problem and solved it with game theoretic method. In the case study, we help decks find the Nash Equilibrium point and their individual ideal price strategy at the Nash Equilibrium point. Moreover, we consider the influence from different groups of customers on the revenue of decks, according to which decks may apply various strategies to manage their customer weighting so as to optimize their revenue.

In the future, Intelligent Transport System would be a potential factor to carry the study as another influence on the customers' response from the decks. And as another operation method, real-time decision making could be applied to be compared against day-ahead operation. As the number of EV customers grows, constraints such as the number of EV

charging outlets as well as parking spots in a deck need to be considered. We will also extend our system to various location based environment such as urban area and rural area to specify location effect and universalize our system.