# A non-sensor solution for effective and inexpensive parking management: payment, reservation, and dynamic pricing

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## 1 Project overview and background

### 1.1 Overview

In this project, a non-sensor based parking management system is proposed. Comparing to traditional on-street parking management schemes, the proposed system is more advantageous in the following ways: (1) Providing better estimates for real-time parking occupancy without deploying sensors; (2) Applying dynamic parking rates based on both demand and supply. (3) Offering parking reservations via mobile or web; (4) Enabling convenience and straightforward parking payment; and (5) Allowing cheap and efficient parking enforcement.

### 1.2 Introduction

On-street parking management has always been painful. Information regarding occupancies and violations are usually difficult to acquire, although various sensing technologies have been utilized in modern on-street parking management systems. Relatively low reliability of sensors and the high expenses of installing and maintaining parking sensors make it not scalable. Moreover, parking rates for on-street parking is usually fixed, which is essentially inefficient, as the actual parking demand is fluctuating day to day. A flexible and dynamic price can increase the overall usage of parking resources in an efficient way.

To conquer the drawbacks of traditional parking and payment schemes, various studies regarding on-street parking management have been conducted in recent years. Parking reservation schemes based on Internet are widely recognized and explored in literature[1, 2, 3, 4]. Some of them discussed the architecture of reservation systems and communication protocols. For example, Wang et al. [5] developed web- and smartphone-based reservation systems for parking lots, and Wang et al. [6] used short message systems in their reservation scheme. In studies of [7, 8], the hardware and software implementations of the reservation system was described. Meanwhile, some other studies focused on policies of parking reservation. Liu et al. [1] analyzed the feasibility of expirable parking reservations, whereas Kaspi et al. [2, 9] explored vehicle sharing regulation via parking reservations, along with a case study using data from Capital Bikeshare in Washington D.C. [9]. Yan et cl. [4] proposed a user-to-user parking spot trading system which requires the usage of mobile devices and availability is not guaranteed for reservations. Parking data of San Francisco downtown areas is used in the system evaluation.

In terms of real world implementations, more public and private garages start to accept online parking reservations, including airport, hotel, national/state parking as well as employee-only parking lots. Most of the systems offer reservations as a daily, monthly or one-time pass, but spot-by-spot

management and fine-grained real-time control is rare. For example, For the purpose of relieving congestion, Yosemite National Park launched a pilot program in June 2016 where visitors can reserve a guaranteed parking space for the whole weekend; DOT of New York City offers monthly municipal garage reservations. To our best knowledge, there has not been a report of public on-street parking with the reservation capability.

In addition, dynamic parking has also been studied to mitigate congestion and reduce parking cruising time. In recent years, they have been tested in pilot areas. The SFPark project of the city of San Francisco includes rate adjustment every month with an attempt to target an optimal parking occupancy. The LA Express Park project also implemented dynamic pricing since August 2012. Seattle Department of Transportation is also installing new parking meters where prices are adjusted based on demand since 2014. Based on data collected from pilot areas, several studies are conducted with the focus on assessing the influence of dynamic pricing on parking choices and occupancies[10, 11]. Teodorovi et al. [12] analysed the optimal pricing scheme with the assumption that future traffic arrival patterns are known. Tsai et al. [13] introduced a pricing model to making reservation cost equivalent to the value of reduced cruising time. Qian et al. [14] proposed a dynamic pricing model for optimizing recurrent morning commute. Liu et al. [1] also incorporated dynamic pricing within the expirable parking reservation. Zheng et al.[15] considered both garage parking and on-street parking when formulating dynamic parking pricing.

In this proposal, the proposed on-street parking management scheme integrates novel technologies of payment methods, statistical modeling, dynamic pricing and big data analytics, intending to offer a more efficient, resilient and convenient on-street parking system for both managers and users. The proposed parking management system brings convenience to the general public by providing real-time parking occupancy and pricing information, and allowing parkers to make parking reservations in advance. The system also features an incentive-based violation reporting scheme that can reduce both the workload of parking enforcement patrolling and parking violations. Moreover, dynamic pricing algorithms [14] will be implemented in this project to maintain parking occupancies within a reasonable range.

Specifically, the proposed parking management system provides the following unique features:

1. **Online parking reservation**: Users are able to make parking reservations via mobile or web applications, by paying an extra amount of premium fee. If their parking spots are taken by other unpaid vehicles, they will be assigned another spot and get refund. Also they will be given additional compensation for the inconvenience.

   By using the associated mobile or web app, users can register an account with credit card info and their license plate number, so that they only need to select parking location and desired parking durations when making an reservation.

2. **Incentive-based violation reporting scheme**: For those parkers who find their reserved spots occupied by some other vehicles, they can report violation via their mobile app and the nearby kiosk. A parking credit will be issued to them, which is charged from the violated vehicle as part of their fine. Moreover, since all parking spots are marked with LED light indicating their current reservation condition, other travelers/pedestrians passing by can also report parking violations via mobile app or the kiosk. They will obtain parking credit issued to their parking accounts towards their next parking journey. This feature will help reduce parking violations and improve the accuracy of occupancy estimation based on transaction data.

3. **Pay as you park**: In additional to violation reporting, this system allows parkers to check-out earlier than their scheduled session expiration time and get partial refund. All reserved or non-reserved parkers who wants to leave earlier have the option to checkout via their mobile app or kiosk, they will get partial refund for the not-yet-parked part of their payment, i.e 80%. Once the parker checks out, his/her spot will be marked available with the green LED on immediately. This feature offers several advantages. First, parkers get more flexibility when paying for parking, and can worry less about overpaying or underpaying. Second, it will improve the efficiency of on-street parking by increasing usage and reducing potential waste. Third, it also serves as another incentive for people to follow their parking schedule closely, which in turn increases the performance of parking occupancy estimation.

4. **Dynamic parking rate**: In order to target an optimal parking occupancy, such that 80% to 90% occupied, the parking rate will be dynamically adjusted according to time of day and real-time occupancy, estimated via transaction and reservation data. Parking rate goes up as the number of estimated available parking spots declines, and drops back once spots become vacant. Pricing information will be displayed on large LED digits that is visible to pass-by parkers. Users can also check parking rates online.

5. **Real-time smart spot allocation**: To maximize the utility of parking resources, parking spots for reservations will be assigned ahead of the start time of reserved sessions. Parkers will receive push notification/email/text message regarding their assigned spots, or they can check it on the kiosk upon arrival.

   The reason for introducing this mechanism is trying to make those currently vacant spots available as long as possible, so that those non-reserved parkers will not find themselves parked in a spot that is only available for a short period of time, say, 20 minutes, and have to come back and make space for those reserved parkers. By arranging reservations with this smart spot allocation, the parking system will be efficient and convenient for both reserved and non-reserved users.

## 2 System Design and Components

In this section, we discuss the design of the proposed parking management system as well as its hardware components.

### 2.1 System Design

The design of the parking management system is described in Figure 1.

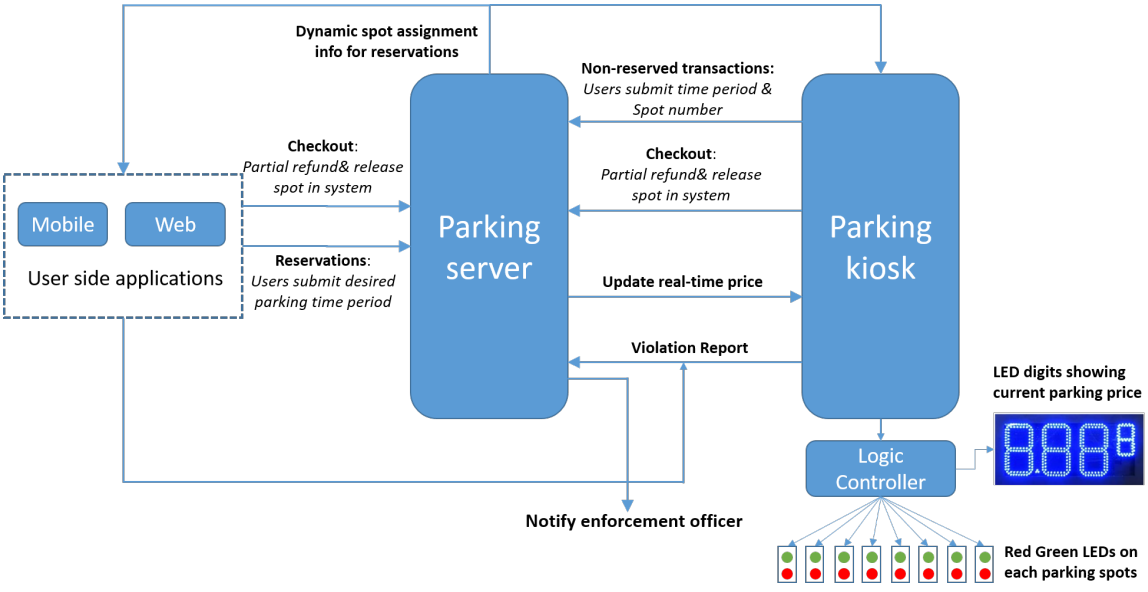


Figure 1: System framework and information flow chart

The web/mobile application handles user reservations and communicate with the parking server. The parking server will update spot assignments and price changes for the parking kiosk as well as web/mobile applications. The logic controller is connected to the parking kiosk, translating kiosk commands into electrical signals. In addition, the parking server processes all violation reports. It will notify the enforcement officer, issue refund to users, and offer parking credit.

### 2.2 Parking kiosk

Similar to traditional on-street parking kiosks, the kiosk in this project features a touch screen and a credit card reader. It uses the cellular network (i.e., LTE) to communicate with the cloud-based parking server. Parkers enter plate numbers and spot numbers to pay for parking. For parkers with reservations, they can use the kiosk to check-in and see their assigned spots on the kiosk. Also, people can report for violation, and check current parking rates.

There will be large LED digits display pad around the kiosk displaying real-time pricing information. Parking rates on the tubes should be visible to parkers driving by the kiosk.

Since the kiosk is mounted outdoor, it should be water/snow proof and with low-temperature endurance.

### 2.3 LED lights on parking spots

To indicate the current availability condition of each parking spot, two LED lights will be installed for each parking spot, one green LED light and a red LED sign marking 'Reserved'". Only one of the two light should be on at a time. When the green LED is on, it means that there is no reservation hold for this spot within the following 15 minutes; and the Red LED indicates that this spot is reserved currently or within the following 15 minutes.

All the LEDs are connected to a logic controller kit via wire, which is then connected to the parking kiosk via either USB or Bluetooth.

### 2.4 Parking server

The parking server is set to handle all requests sent from parking kiosk as well as the mobile/web application. It will process all payments and reservations, estimate/predict occupancy information, dynamically adjust parking rates, and send updates to parking kiosk. It can assign spots for upcoming reservations and notify parkers via push notification/email/text message. Whenever a violation report comes, the server will notify the enforcement officers and handle refunds.

The parking server will be configurated with the combination of Nginx/Django/MySQL.

### 2.5 Mobile and web applications

The mobile and web application serves as a remote and portable parking kiosk for users. Users are able to create accounts, make or change reservations, pay for parking, check out parking sessions, extend current parking sessions, check real-time pricing and availability information, and report for parking violations.

Users need to register personal accounts for the first time they are using the mobile or web app. The account will save their credit card info, license plate numbers and favorite parking locations for future convenience. Users select parking location and enter desired parking duration when making reservations. For non-reserved (walk-in) parking, the users can simply enter the spot number and parking duration via their mobile app (given the spot is available).

## 3 Functionality description

This section describes the process of parking and payment from the user perspectives.

### 3.1 Reservations and payments

The proposed parking management system allows users to reserve a parking space at a specific time period, with an additional premium fee. The premium fee is not refundable unless the user does not find his reserved spot available. When making reservations, users choose their desired parking location and period of time/date, but cannot designate a parking spot. Spots are dynamically assigned by the parking server in order to maximize space usage, at the same time accommodating non-reserved (walk-in) parkers.

For non-reserved (walk-in) parking, there will be LED lights on each spot informing parkers of the availability at the present time. Parkers need to enter plate numbers as well as the parked spot numbers to complete their parking transactions. The walk-in parker will be provided the duration up to the next reserved session for purchasing his session. He has to be vacated 15 min before the next reserved session starts.

### 3.2 Parking price

In this project, time-dependent parking prices as well as dynamic pricing schemes [14] will be used to keep parking occupancy optimal, for example, 80% to 90%.

For time-dependent parking prices, the time of day will be divided into few periods, each has a different base price according to historical occupancy information. On top of that, a dynamic pricing scheme will be implemented as the real-time parking rates can be adjusted according to real-time occupancies.

People who make parking reservations early will be able to pay for only based price and an additional non-refundable premium fee. When excessive amount of reservations are received for a certain period of time, parking rate for subsequencing reservations will increase. However, the price for non-reserved parkers may drops under based price if the real-time occupancy is significantly lower than usual.

### 3.3 Spot assignment

As discussed before, people can not designate their parking spots when making reservations, the parking server will ensure that a spot will be available for their reserved parking sessions. In case of parking violations, another spot will be assigned immediately if possible, or the premium reservation fee will be refunded along with a parking credit for compensation.

The availability of parking spots will be indicated by LED lights. When the Red light is on, no parkers except the one who make the reservation can park on the spot. To avoid conflict, the assigned spot for upcoming reservation will show red light 15 minutes ahead of time.

Spot are assigned by the parking server in a way to maximize the duration of vacant time of all available spots. By doing this, the probability of a walk-in parker find no spot, though currently available, fit into his desired parking period is minimized, unless it is impossible to create such a vacant parking period for all available spots.

### 3.4 Violation reporting

For parkers finding their reserved spots occupied by some other vehicles, they can report violation via parking kiosk or their mobile/web app. A new parking spot will be assigned if possible, or they will get refund along with a parking credit for compensation. This triggers a notification sent to the enforcement offers for potential violations. The parking credit is charged from the violated vehicle as part of their fine. The parking credit can be in the form of a promo code, and can be applied to an account.

Each currently vacant spot will be indicated by a green LED light on top of that, and each reserved or purchased parking spot will be marked with a red LED as ”Reserved”. In this way, any vehicle parked in a spot with green LED on is clearly unpaid parking. Anyone can report parking violations as well. Upon validation by the enforcement officer, the reporter will get a parking credit.

Such a violation reporting scheme will significantly reduce the amount of parking violations as they will be caught and cited more easily. The scheme will reduce the patrolling frequency of enforcement officers as they can stop on the needed basis.

## 4 Scenarios

In this section, a few cases regarding the actual usage of the system are described to demonstrate how those proposed features work together.

### 4.1 Reserve and park

User A makes parking reservation via the mobile app. If he is using the system for the first time, he needs to register an account (with his plate number, and credit card info), fill in a time period of parking, and select the area of the parking spots. The earlier he submits the reservation request, the lower parking rate he is likely to pay for. He needs to pay the additional amount of premium reservation fee to reserve a parking spot.

15 minutes prior to his parking session, the spot ID will be assigned based on current and future parking schedule, and the LED on his/her spot will turn red at that time. He will be informed of the spot ID via push notification on the phone or a text message, or he can check it at the parking kiosk upon arrival. Upon arrival, he use the web/phone app or the kiosk to check in his reservation to start. He will also get notifications when his parking session is about to expire (with the information of the spot being extensible or not, and if so, for how long).

If User A decides to leave 30 minutes earlier, he has the option to check out upon leaving, by tapping checkout on the kiosk or the web/phone app. As a result, he gets a refund of 50% of the unparked 30 minutes, and the spot is immediately mark as green, available for other parkers.

### 4.2 Walk-in parking (no-reservation)

User B wants to park but did not make a reservation. She can check the current parking rate on her mobile app. If she cruises around the parking kiosk, she can also see the rate on the LED pad. She can choose one spot with a green light on to park, and pay for parking on mobile app or kiosk by inputing her spot number and the duration of her desired session (She will need an account if she pays via the web/mobile app). However, she cannot pay for more than the longest possible parking durations, constrained by the next parking reservation on this spot.

If User B decides to leave 30 minutes earlier, she has the option to check out upon leaving, by tapping checkout on the kiosk or the web/phone app. As a result, she gets a refund of 50% of the unparked 30 minutes, and the spot is immediately mark as green, available for other parkers.

### 4.3 Violation reporting

If User C reserved a parking spot, but come to find out her spot is taken by another vehicle, she can first park on any spot with the green light on, then report for violation and submit her new spot number via either the mobile app or the kiosk. The violated vehicle will get a ticket and possibly be towed. If she parks without reporting violation, then it is possible that she will be reported as a violation since she parks on a green spot.

In case there is no available spot when violation occurs, user C will get her parking fee refunded as well as an additional parking credit as compensation, which can be applied the next time she park. This credit comes from the fine of the violated vehicle.

For user D who is not parking today, if he sees vehicle parking on a spot with green LED on, he can also report that via his mobile app or the kiosk. He can receive a the parking credit after the violation is verified by the enforcement officer.

### References


[1] Wei Liu, Hai Yang, and Yafeng Yin. Expirable parking reservations for managing morning commute with parking space constraints. *Transportation Research Part C: Emerging Technologies*, 44:185–201, 2014.

[2] Mor Kaspi, Tal Raviv, and Michal Tzur. Parking reservation policies in one-way vehicle sharing systems. *Transportation Research Part B: Methodological*, 62:35–50, 2014.

[3] Wu Sun, Kyriacos C Mouskos, and David Bernstein. A web-based parking reservation system. In *82nd Annual Meeting of the Transportation Research Board. Washington, DC*, 2003.

[4] Tingxin Yan, Baik Hoh, Deepak Ganesan, Kenneth Tracton, Toch Iwuchukwu, and Juong-Sik Lee. Crowdpark: A crowdsourcing-based parking reservation system for mobile phones. *University of Massachusetts at Amherst Tech. Report*, 2011.

[5] Hongwei Wang and Wenbo He. A reservation-based smart parking system. In *Computer Communications Workshops (INFOCOM WKSHPS), 2011 IEEE Conference on*, pages 690–695. IEEE, 2011.

[6] QING Wang and QING Wang. Research on public parking reservation system based on sms. 2011.

[7] K Inaba, M Shibui, T Naganawa, M Ogiwara, and N Yoshikai. Intelligent parking reservation service on the internet. In *Applications and the Internet Workshops, 2001. Proceedings. 2001 Symposium on*, pages 159–164. IEEE, 2001.

[8] Gongjun Yan, Weiming Yang, Danda B Rawat, and Stephan Olariu. Smartparking: A secure and intelligent parking system. *IEEE Intelligent Transportation Systems Magazine*, 3(1):18–30, 2011.

[9] Mor Kaspi, Tal Raviv, Michal Tzur, and Hila Galili. Regulating vehicle sharing systems through parking reservation policies: Analysis and performance bounds. *European Journal of Operational Research*, 251(3):969–987, 2016.

[10] Adam Millard-Ball, Rachel R Weinberger, and Robert C Hampshire. Is the curb 80% full or 20% empty? assessing the impacts of san franciscos parking pricing experiment. *Transportation Research Part A: Policy and Practice*, 63:76–92, 2014.

[11] James Glasnapp, Honglu Du, Christopher Dance, Stephane Clinchant, Alex Pudlin, Daniel Mitchell, and Onno Zoeter. Understanding dynamic pricing for parking in los angeles: Survey and ethnographic results. In *International Conference on HCI in Business*, pages 316–327. Springer, 2014.

[12] Dušan Teodorović and Panta Lučić. Intelligent parking systems. *European Journal of Operational Research*, 175(3):1666–1681, 2006.

[13] Mei-Ting Tsai and Chih-Peng Chu. Evaluating parking reservation policy in urban areas: An environmental perspective. *Transportation Research Part D: Transport and Environment*, 17(2):145–148, 2012.

[14] Zhen Sean Qian and Ram Rajagopal. Optimal dynamic parking pricing for morning commute considering expected cruising time. *Transportation Research Part C: Emerging Technologies*, 48:468–490, 2014.

[15] Nan Zheng and Nikolas Geroliminis. Modeling and optimization of multimodal urban networks with limited parking and dynamic pricing. *Transportation Research Part B: Methodological*, 83:36–58, 2016.