Analysis, Design, and Simulation of Advanced Parking Management Systems (P17-21579)

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1. INTRODUCTION

Due to the increasing car ownership, parking has become a major problem in many large cities and downtown areas all over the world. Cruising for parking is time-consuming and frustrating for drivers, and further makes traffic congestion more severe by slowing down through vehicles and increasing traffic volume on roads.

Advanced parking management services, including parking information, reservation and navigation, aim to help drivers find parking spaces quickly. Although the latter two are still in their infancy, the proliferation of advanced smartphones and the development of sensing and wireless communication technologies provide tremendous opportunity for advanced parking management. This dissertation devotes to analyzing the impacts and implications of those emerging parking management services, and providing guidance on their development and deployment.

2. ANALYSIS OF ADVANCED MANAGEMENT OF CURBSIDE PARKING

This section establishes analytical models to compare the impacts of parking information and reservation services on the spatial distribution of parking activities by conducting the analysis in a highly stylized and abstract setting.

Status Quo

- Given that drivers have different risk-taking attitudes, some (risk-averse drivers) will start cruising for parking at spaces far from their destination, while others (risk-seeking drivers) may drive very close to the destination and start from there.
- Take the first vacant space and walk to the final destination.

With Information

- Drivers adopt the same parking search strategy as status quo, but they are able to select an optimal location to start their parking search such that their walking time to the final destination can be minimized.

With Reservation

- Drivers are assumed to reserve the vacant one closest to the destination when they enter the street.

SteadyState

status quo

$$p_i = \begin{cases} \frac{\gamma}{\gamma + c_N \lambda}, & i = N \\ \frac{\gamma p_{i+1}}{\gamma p_{i+1}^2 + (c_i \lambda - \gamma) p_{i+1} + \gamma}, & \forall i = N-1, \cdots, 0 \\ \frac{p_{i+1}}{p_{i+1}^2 - p_{i+1} + 1}, & \forall i = -1, \cdots, -L \end{cases}$$

with information

$$p_i = \begin{cases} \frac{\gamma}{\gamma + \lambda}, & i = N \\ \frac{p_{i+1}}{p_{i+1}^2 - p_{i+1} + 1}, & \forall i = N-1, \ldots, -L \end{cases}$$

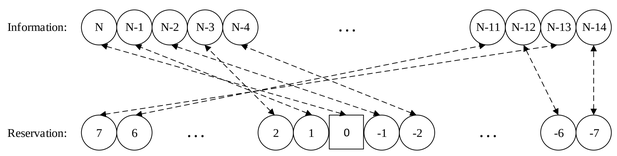

FIGURE 1 The relation between parking with information and reservation service

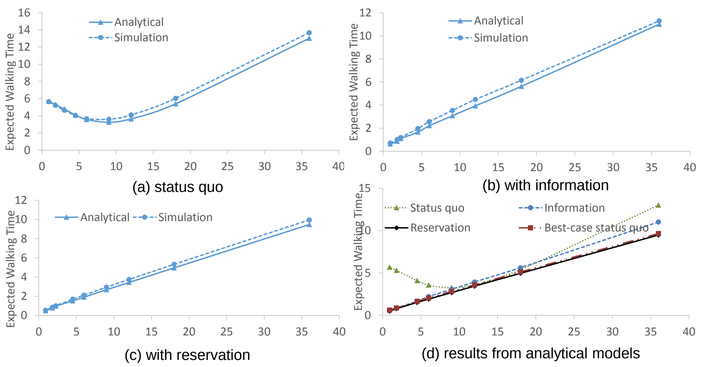

FIGURE 2 Expected walking times from analytical model and simulation ((a)-(c)); and results from analytical models (d)

3. PARKING RESERVATION FOR MANAGING DOWNTOWN CURBSIDE PARKING

This section designs a smartphone-based parking reservation system that manages a finite number of curbside parking spaces in a downtown area in a way to minimize the social cost of parking, considering the impact of drivers' private information (e.g., destination) on the parking cost.

Incentive to Lie

$$e_{ij} = \alpha t_{ij} + \beta w_{ij}$$

The locations of vehicle i and space j

The reported final destination

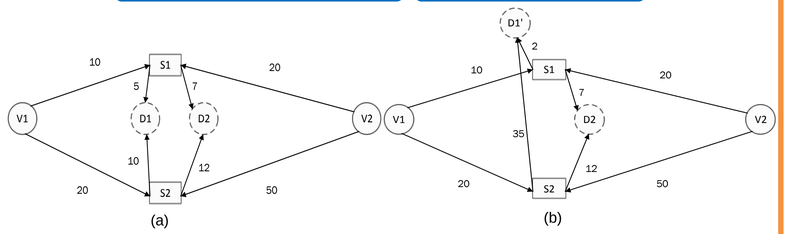

FIGURE 3 Parking reservation scenario with (a) true and (b) misreported information

- (a): (V_1, S_2) and (V_2, S_1), and the total cost is 57
- (b): (V_1, S_1) and (V_2, S_2), and the total cost is 77

Parking Fee Design

Each driver is assessed with a parking fee equal to the harm she causes to the other drivers, i.e., the parking fee for driver i:

$$T_i(X^*; \hat{e}) = \sum_{k \neq i} P_k(X^*; \hat{e}_k, \hat{e}) - \sum_k P_k(X^*_{-i}; \hat{e}_k, \hat{e}_{-i})$$

Total parking cost of the other vehicles when vehicle i is present

Total parking cost of the other vehicles when vehicle i drops out

Proposition 1. Under such reservation scheme, no driver will have incentive to lie, regardless of whatever the other drivers report.

Dynamic Scheme Design

1. Divide the whole planning horizon into a finite number of short time periods.
2. Do the system-optimum assignment for each interval.
3. Assess parking fee on all drivers at that interval.

TABLE 1 Experimental results

Number of Periods	Average Social Cost	Average Revenue	Individual Total Cost
1	161.17	308.56	4.70
2	214.34	267.33	4.82
4	266.47	211.42	4.79
5	283.03	194.77	4.78
10	329.20	119.20	4.48
20	371.84	70.54	4.42
50	395.11	32.77	4.28
100 (FCFS)	424.47	0.00	4.24

Revenue Redistribution

Redistribute the revenue to drivers without affecting their incentives to tell the truth:

$$Z_i = \frac{\sum_{l \in I \setminus \{i\}} T_l(X^*_{-i}, \hat{e}_{-i})}{N}$$

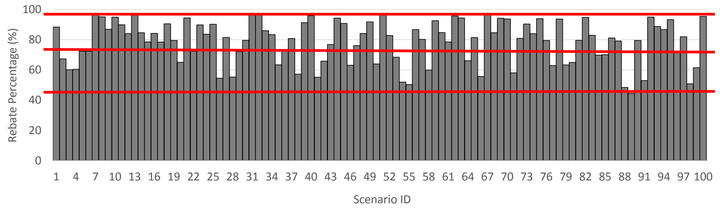

FIGURE 4 Percentage of revenue redistributed to drivers

4. ADVANCED PARKING NAVIGATION SYSTEM

This section develops a parking navigation system to manage the public parking spaces in downtown areas.

Stable Driver-Optimal Assignment

- Drivers will be assigned to their most appropriate parking spaces (if any)
- Drivers have no incentive to misreport their private information (e.g., preferences on parking spaces)

Algorithm 1 The driver-oriented deferred acceptance algorithm

Step 1: Each driver requests her most preferred space; **repeat**

Step 2: each space keeps its most preferred application (if any) and rejects the rest (if any).

Step 3: each driver who was rejected at the previous step requests her next acceptable space (if any). **until** no driver requests in the last step.

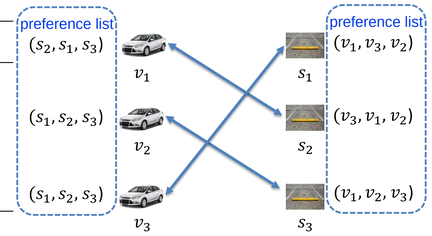

FIGURE 4 Stable driver-optimal assignment

Distributed Stable Match

- Minimum centralized coordination is required, and drivers' private information will not be disclosed

FIGURE 5 Procedure of the parking navigation system

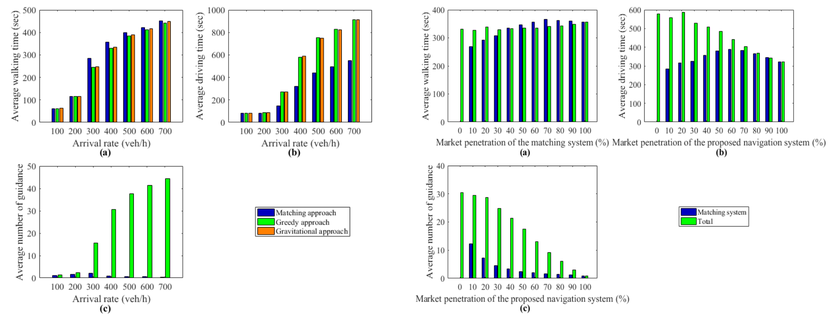

FIGURE 6 Relations between arrival rate (left) and market penetration (right) and (a) average walking time, (b) average driving time, and (c) average number of guidance

5. MICROSCOPIC PARKING SIMULATION

This section propose to construct an agent-based microscopic parking simulation model. Based on a real network in San Francisco, different scenarios, including status quo, with information provision, and with reservation service, are conducted as application examples to demonstrate the proposed simulation tool.

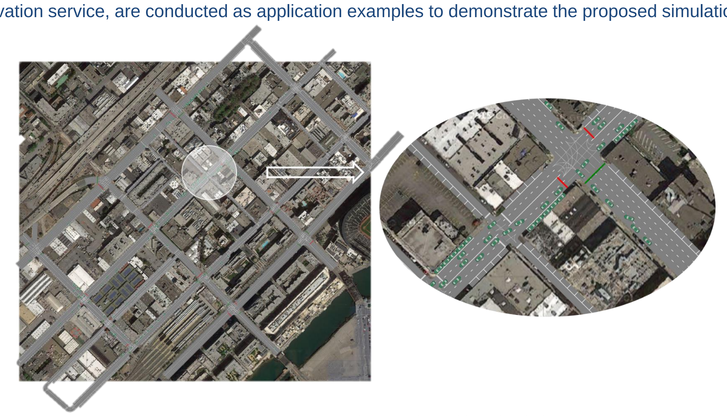

FIGURE 7 Microscopic parking simulation