Demand Management for On-Street Parking

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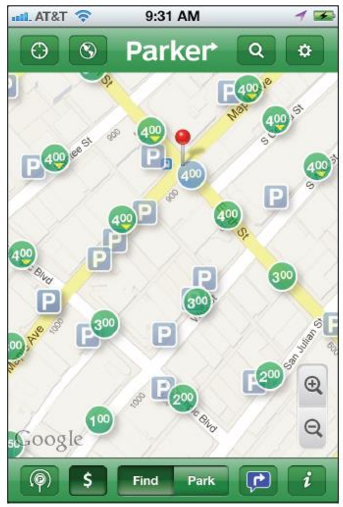
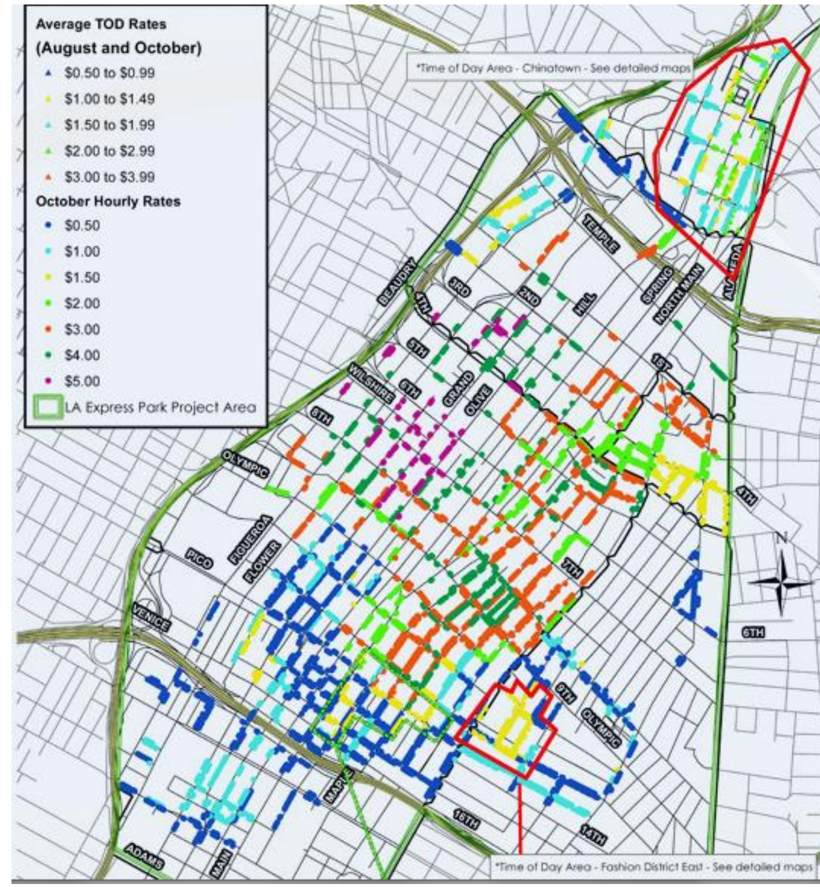
New solutions enabled by sensor and communication technologies

Real-time occupancy data for all down-town LA on-street parking spaces (close to 7000).

Streetline's Embedded Sensor





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Contribution: Smart Pricing Algorithms

To target ~85% parking occupancy through pricing

1. Prices close to market rates ensure most efficient use of the limited resource.
2. “Cruising” for parking (congestion and pollution) is reduced.
3. Extra revenue can support expansion of transit network and other initiatives.

Approach 1 Time-of-day:
Revise schedules at the end of the month

In operation

Approach 2 Adaptive pricing:
Change prices more frequently based on demand

Will pilot

William Vickrey (Nobel Prize 1996), 1954.

II. THE ECONOMIZING OF CURB PARKING SPACE— A SUGGESTION FOR A NEW APPROACH TO PARKING METERS

Uncontrolled parking of automobiles on the streets in large cities produces extremely unsatisfactory results both in terms of impeding the flow of traffic through the streets, and in causing would-be parkers to spend an undue amount of time and effort in finding a place to park and in making it in many cases impossible for persons who need to get to a given destination in a hurry to find a parking space within a reasonable distance of their destination. In addition, dense parking may make it difficult for trucks to make deliveries, may cause double parking for such

Vickrey's ex-post meter and the 85 % rule

Vickrey proposed an ex-post meter:

20 connected nearby meters

rate on the meter is a function of how many are occupied:

1-17 : relatively low

18-19 : high

20 : very high

Ex-post meters have several problems

- Hardware not ready
- Acceptance issues
- It puts prediction task on shoulders of drivers, yet system has all data and computing power!

Pricing models and *social welfare*

Two spots, one time period, valuations for parking {8,2,4,12}.

Maximal social welfare:

{8,2,4,12} : 8 + 12 = 20.

First-come first-served:

{8,2,4,12} : 8 + 2 = 10.

Fixed meter price of 3:

{8,2,4,12} : 8 + 4 = 12.

VCG mechanism (e.g. for residential parking):

{8,2,4,12} : 8 + 12 = 20. [Maximal]

Demand management:
Increased efficiency instead of extension.

Road access, parking, and public transport.

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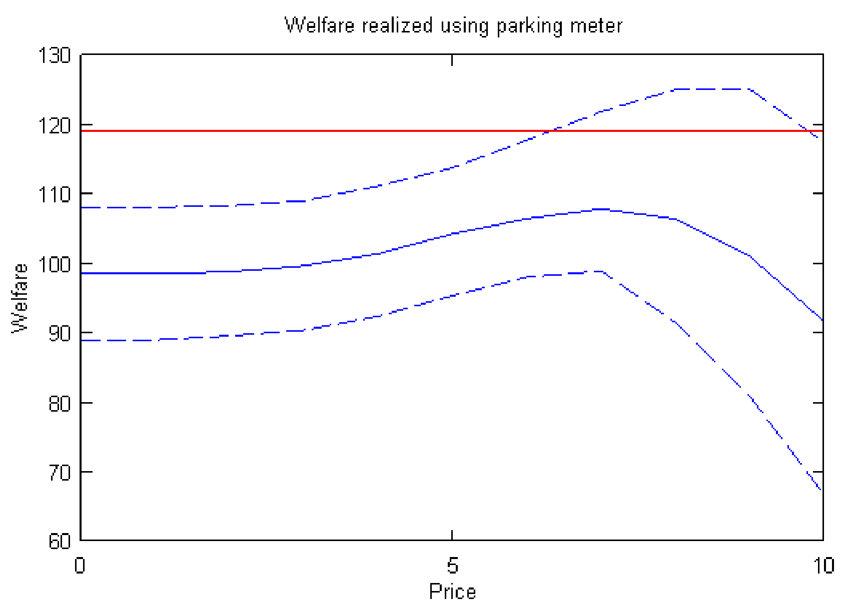
Auctions, posted-prices, the 85% rule, and disappointments.

Observation: for *these* valuations any price $p \in (4,8]$ achieves maximal social welfare:

{8,2,4,12} : 8 + 12 = 20.

Valuations are **stochastic** $v_1, v_2, \ldots \sim P(v_1, v_2, \ldots)$.

Goal: find price that is *"good"* in expectation.



Take home messages from this study:

- A higher price can increase welfare.
- The last % of revenue hurts welfare.
- Variation can be large.
- The 85 % rule does not guarantee availability of free spots: disappointments.

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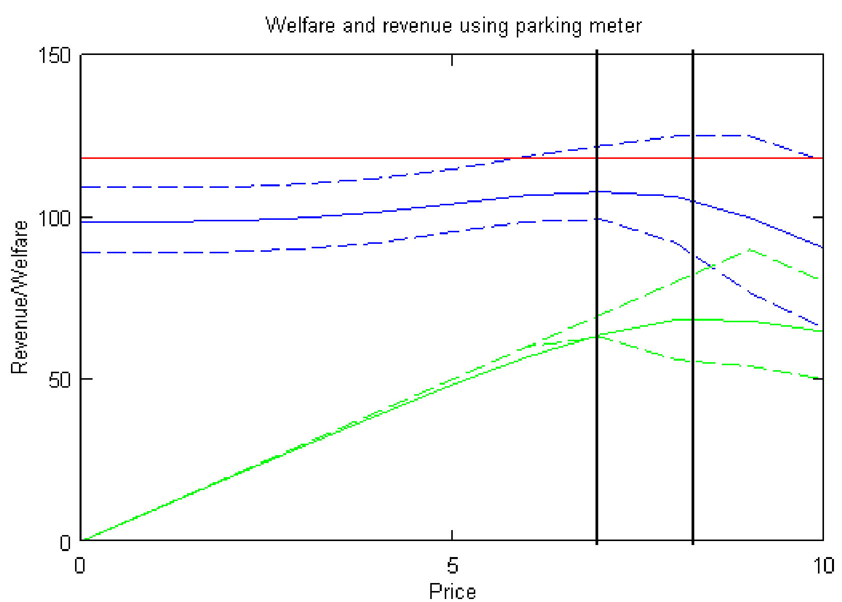

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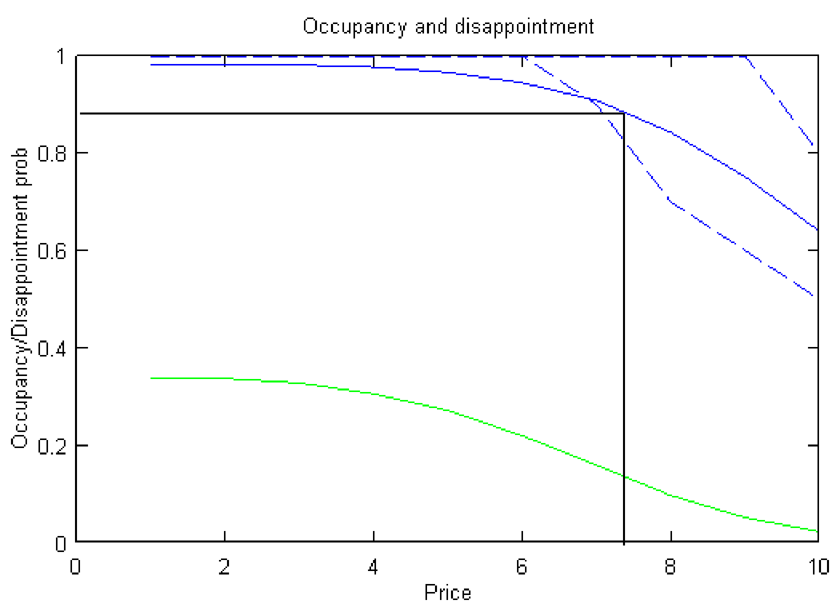

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Beyond a Poisson-Gamma model

What is a "worst-case" distribution?

Everyone has same value.

What is an "ideal" distribution?

Two groups high/low that are separated, e.g. employees/shoppers.

Duration is a big differentiator: walking cost is amortized over a longer stay.

Elements of the rate changing logic

$$\int U(x,p)P(x|p)dx$$

Utility   Parking demand

$$U(x,p) = \sum_{\text{actors}} u_a(x,p)$$

Several levels of sophistication
- Parkers
- Drivers
- Inhabitants
- Downtown businesses
- ...

As a simple example utility model let us focus on two groups: parkers and drivers

Underutilization:
Bad if many spaces are available (occ<70 %) while p>0:
useful parking might have been diverted

Overerutilization:
Bad if blockface is nearly (occ >90 %) full:
parkers blocked and congestion due to cruising

This is one interpretation of city goals of staying close to 85 %

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Elements of the rate changing logic

$$\int U(x,p)P(x|p)dx$$

Utility Parking demand

Vanilla solution: Change rates based on average occupancy has a weakness: A too busy afternoon combined with a too busy morning can average to a perfect 85 % .

Average utility ≠ Utility of the average

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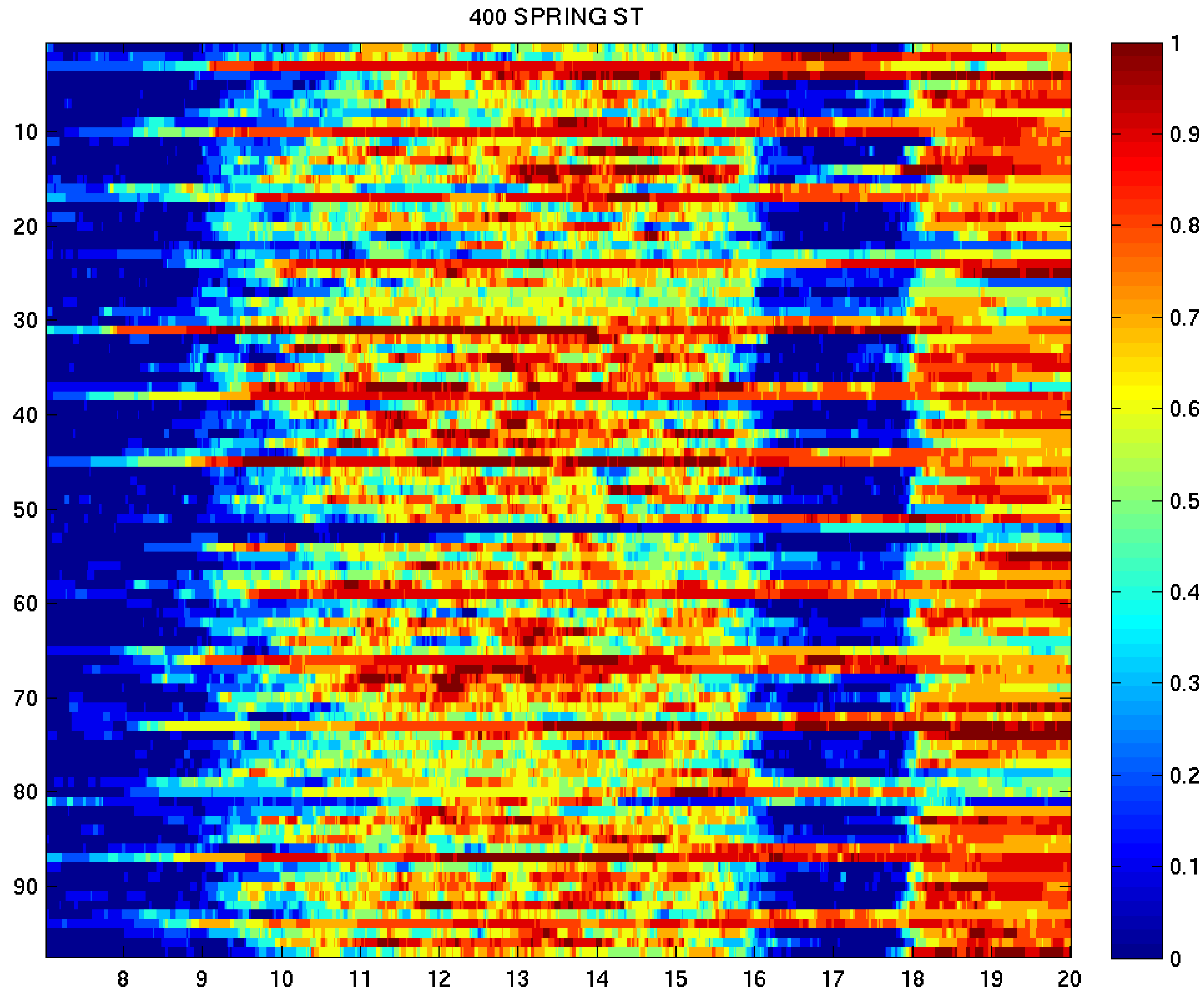

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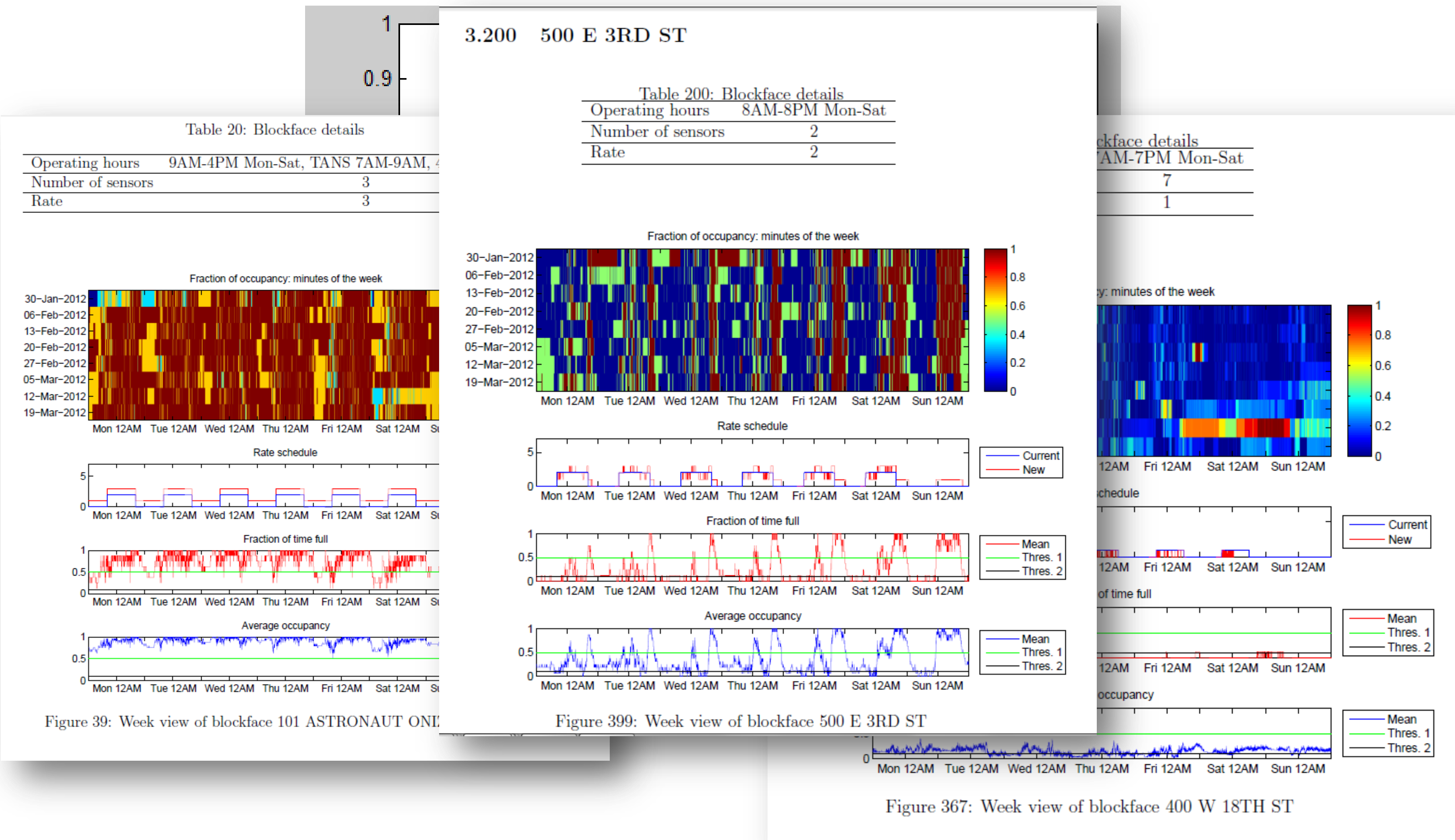
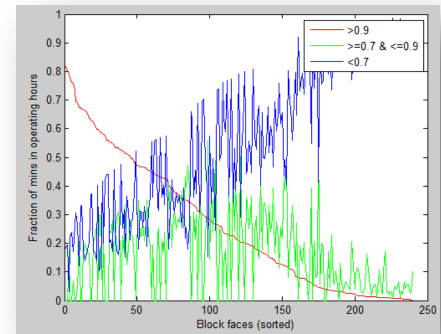
Pricing engine, objectives, algorithms.
A glimpse

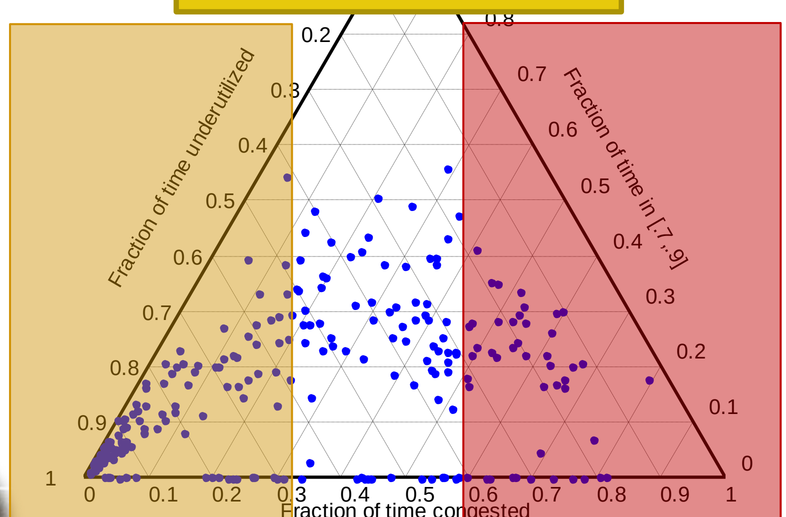


Pricing engine, initial objectives.
A glimpse

We can represent this data using a *ternary* plot



Don't change the rates here:
Hardly ever too full,
Hardly ever too empty.



Decrease rates here:
Significantly more underutilized than over utilized.

Increase rates here:
Significantly more congested than underutilized

Don't change the rates here:
It is both congested a reasonable fraction of time (suggesting rate increase),
but also underutilized a reasonable fraction of the time (suggesting decrease).
A single rate can't solve both: wait until Phase II, time-of-day pricing

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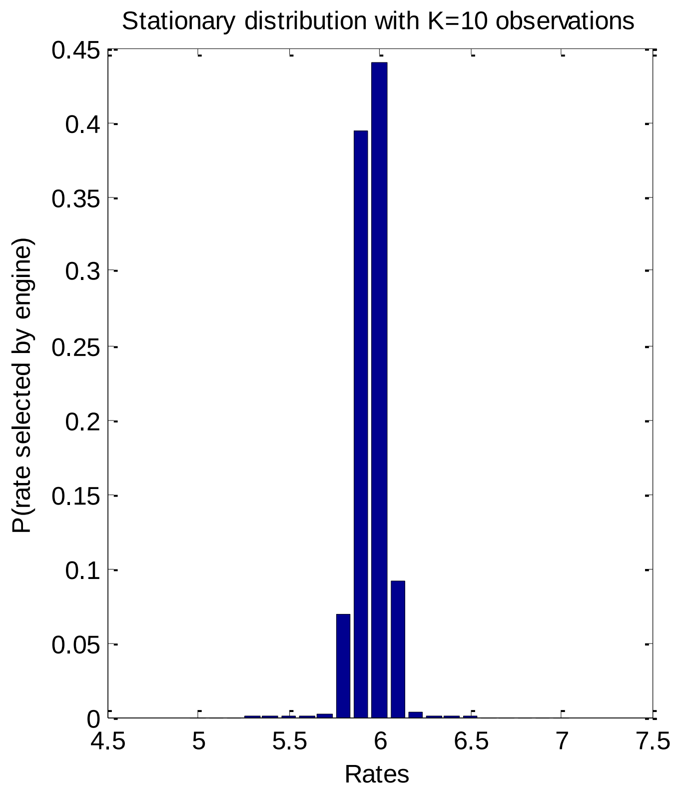
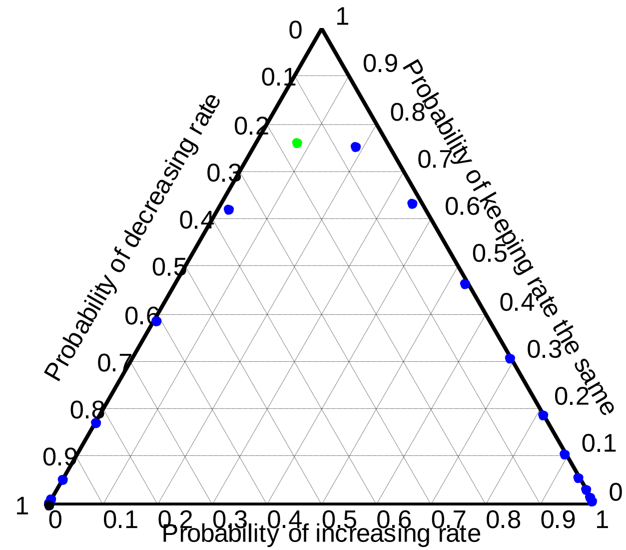
A Markov Chain on rates and a convergence to a unimodal distribution

Rate at time t is $r_t \in \{0.5\ 1\ 1.5\ 2\ 3\ 4\ 5\ 6\ 7\ 8\}$.

Pricing engine induces a Markov chain with tri-diagonal transition matrix

$$P(r_{t+1} = j | r_t = i) = P_{i,j}.$$





A Markov Chain on rates and a convergence to a unimodal distribution

Rates are kept on a discrete grid.

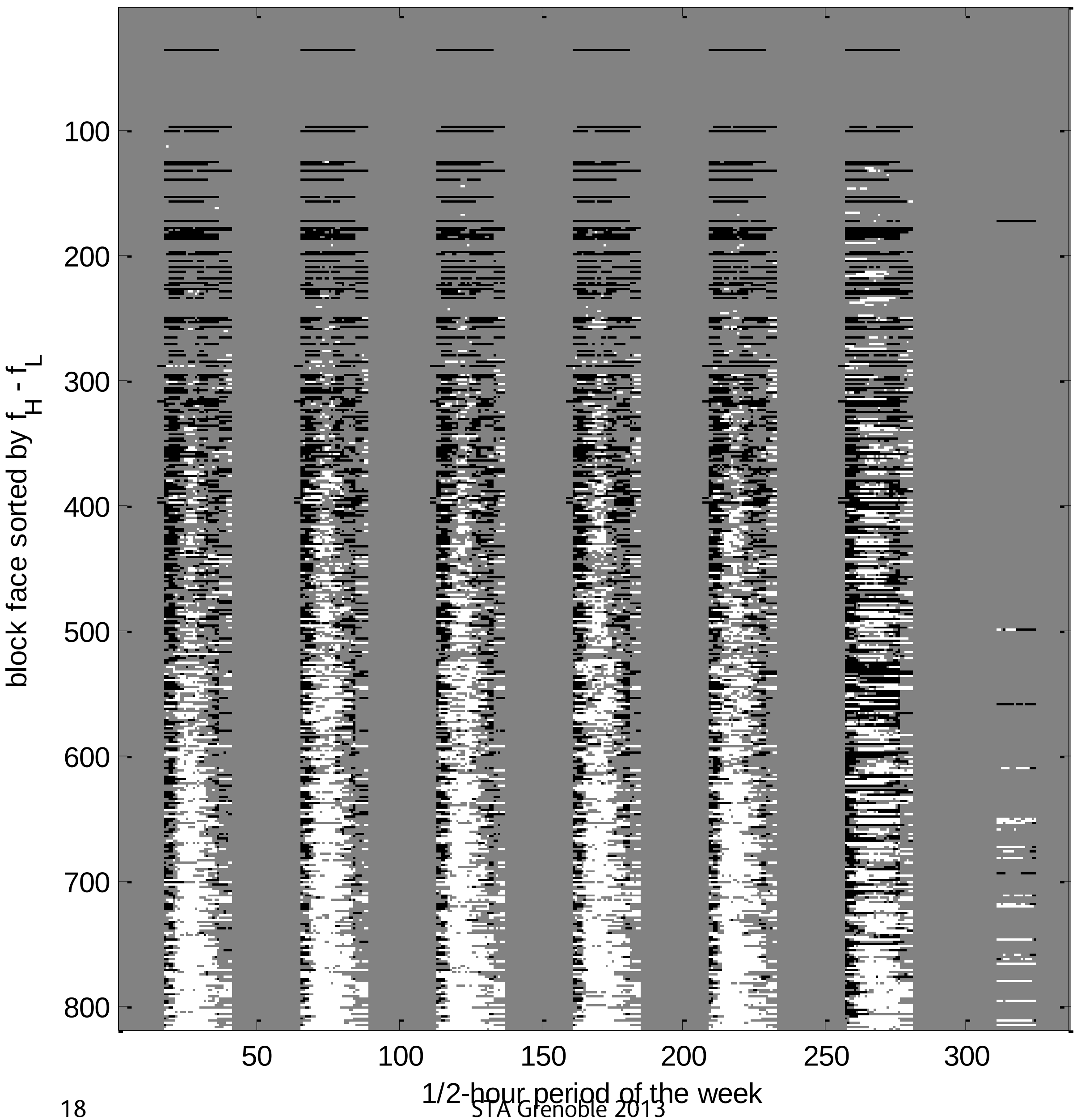
Rate at time t is $r_t \in \{0.5\ 1\ 1.5\ 2\ 3\ 4\ 5\ 6\ 7\ 8\}$.

Pricing engine induces a Markov chain with tri-diagonal transition matrix $P(r_{t+1} = j | r_t = i) = P_{i,j}$.

Lemma For every tri-diagonal transition matrix P there exists a vector s such that $s_i P_{i,j} = s_j P_{j,i}$ for all i and j.

Theorem If the demand distribution is stationary and the rate change rules are such that $P_{i+1,i+2} \leq P_{i,i+1}$ and $P_{i+2,i+1} \leq P_{i+2,i+1}$ for all i, the stationary distribution s over rates is uni-modal with a mode at the smallest i with $\frac{s_{i+1}}{s_i} = \frac{P_{i,i+1}}{P(i+1,i)} < 1$, or L if there is no such i.

Need for time-of-day pricing



Key:

Black - price down;

Gray - price same or un-priced;

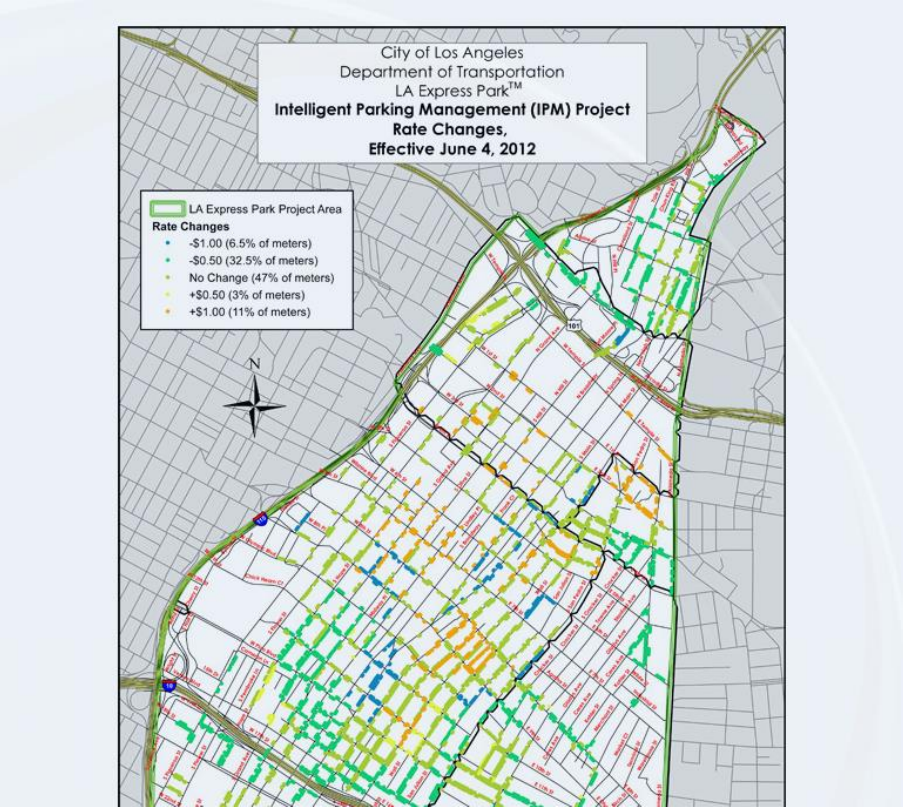
White: price up

Data: 4 weeks from 4-Jun-12

Interpretation:

1. If different half hours in the day suggest different changes to the rates, ToD pricing can be beneficial.
2. Blockfaces are sorted by the number of half hours suggested for increase.
3. Blocks at the top and bottom don't need ToD. Blocks in the middle have mid-day peak.
4. The period of low occupancy before 10 AM is common

First changes went into effect June 4th 2012

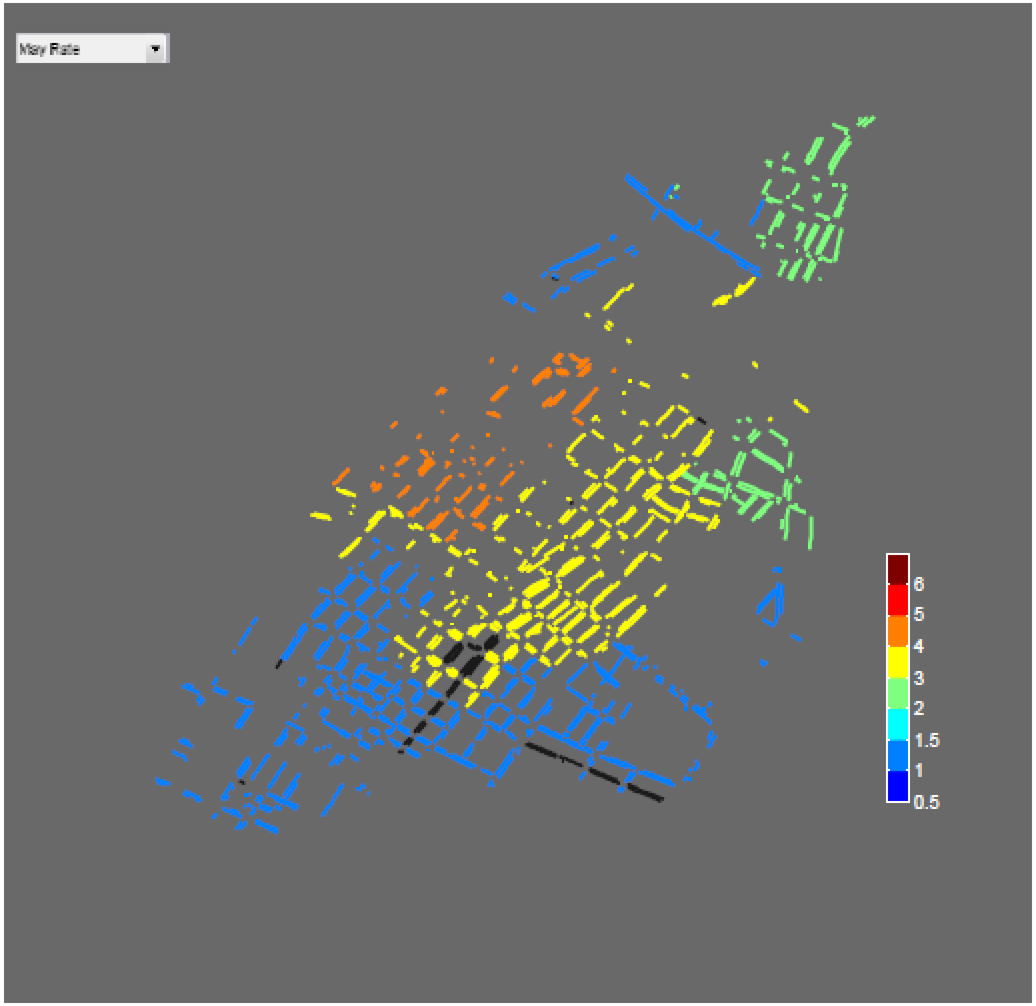


Of all blockfaces in pilot area:
- Decreased rates: 39 %
- Increased rates: 14 %

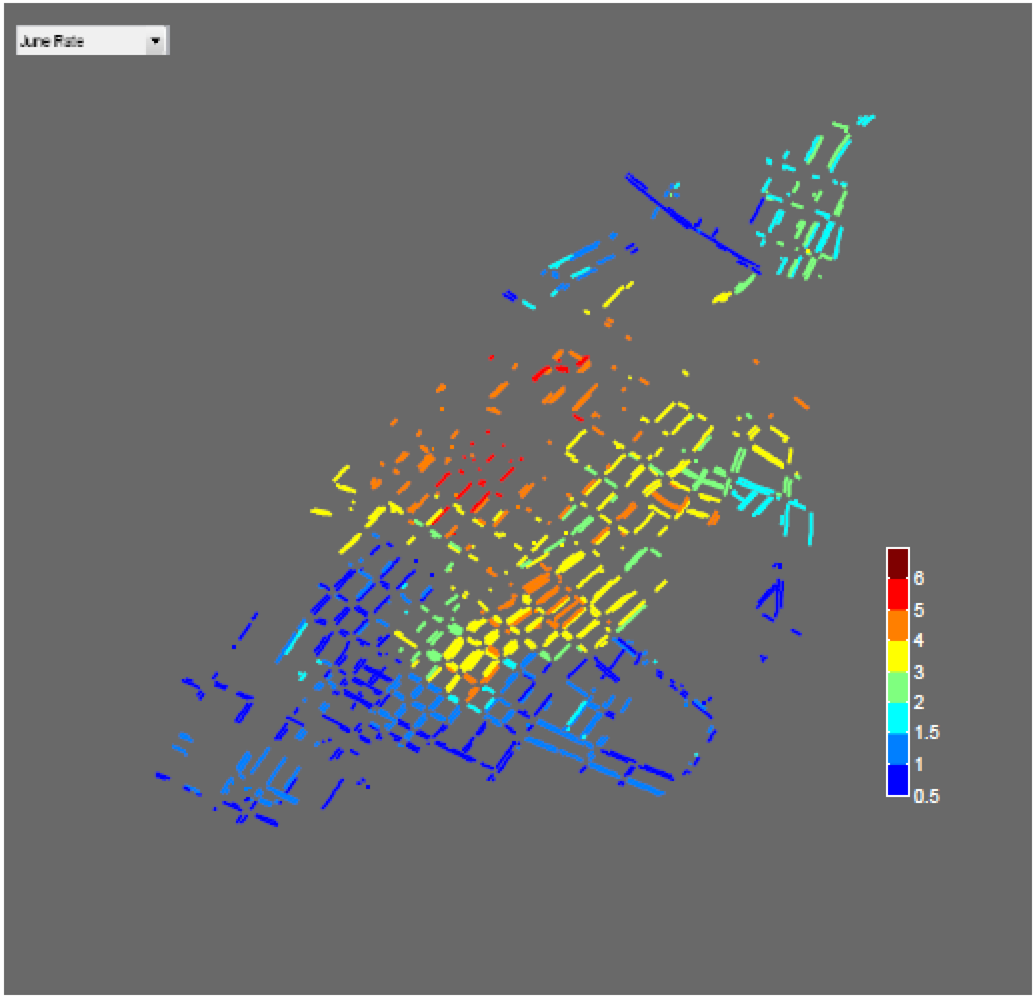
Data driven updates
- All changes supported by data using easy visualizations.

All expensive locations have a cheaper alternative nearby.

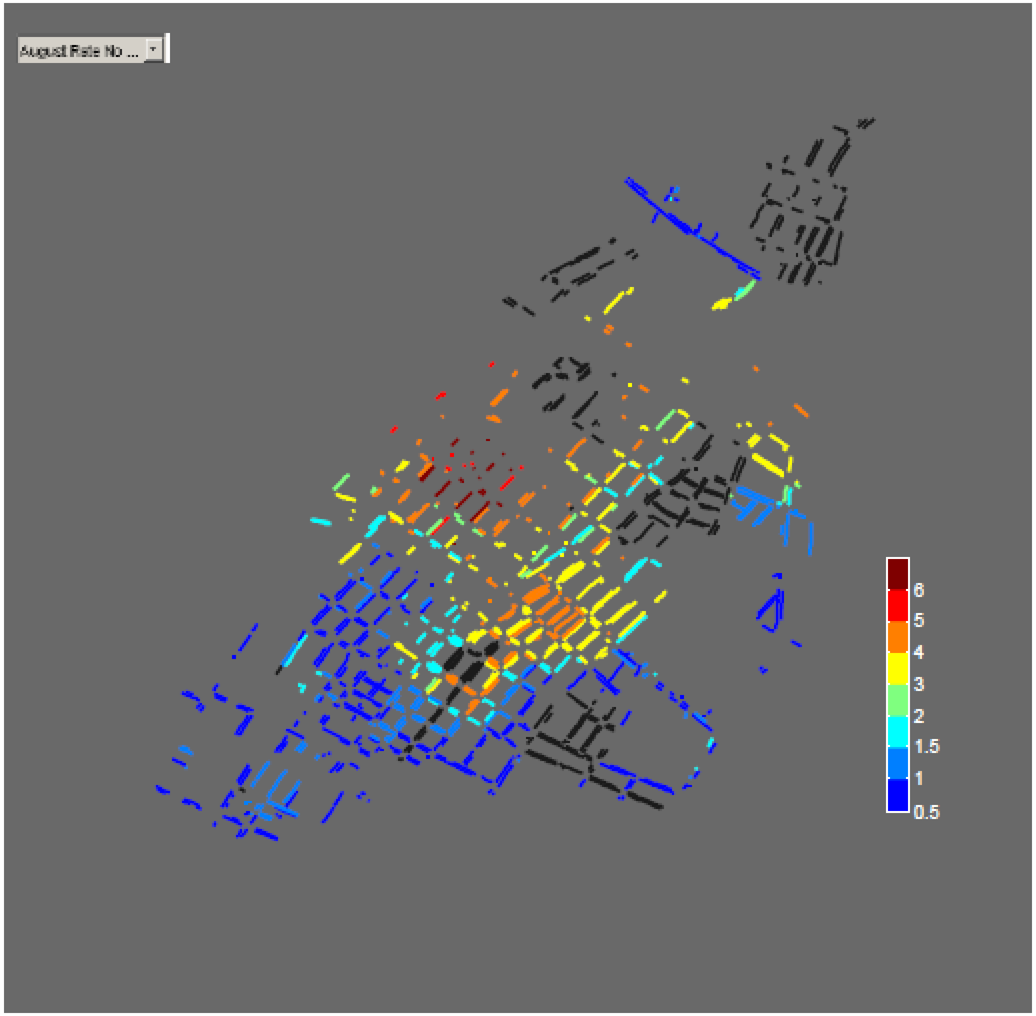
May rates (before start of pilot)



June rates (after first rate change)



August rates (flat rate areas)



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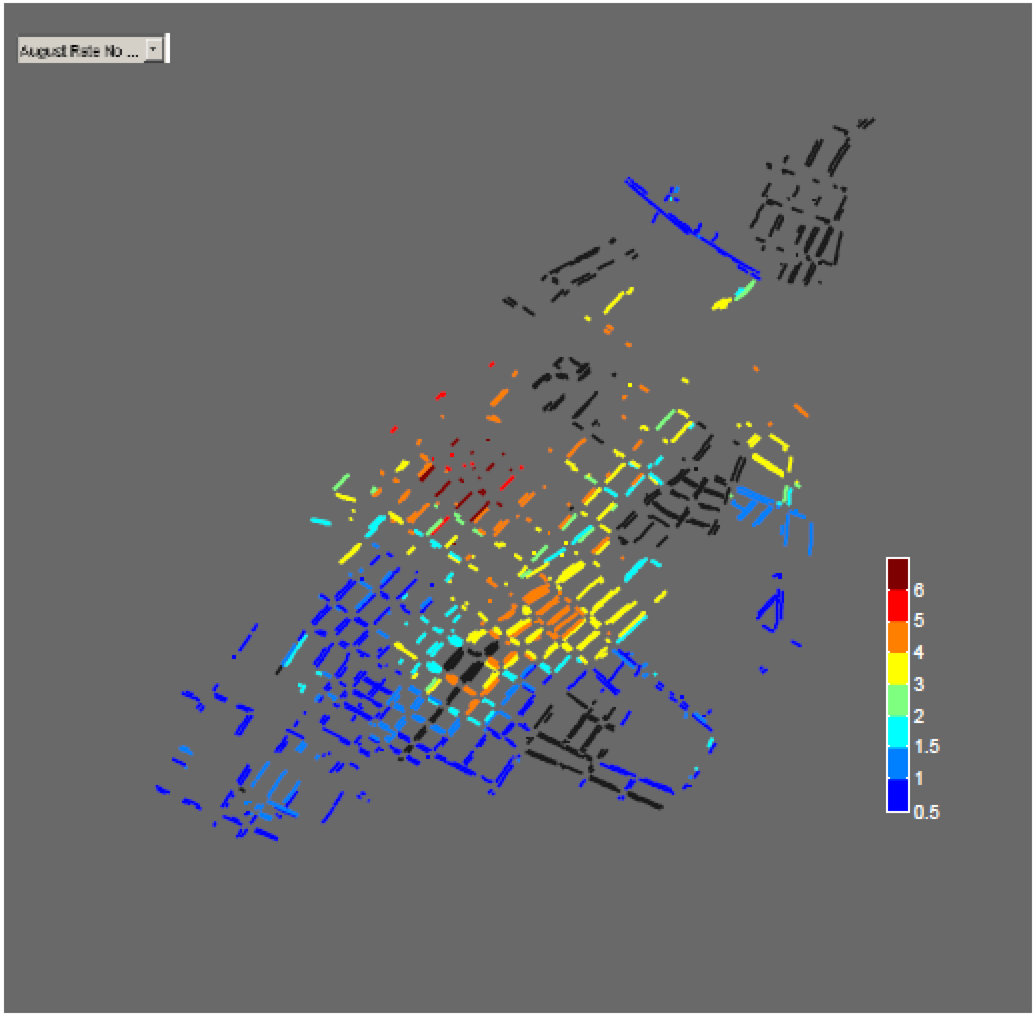
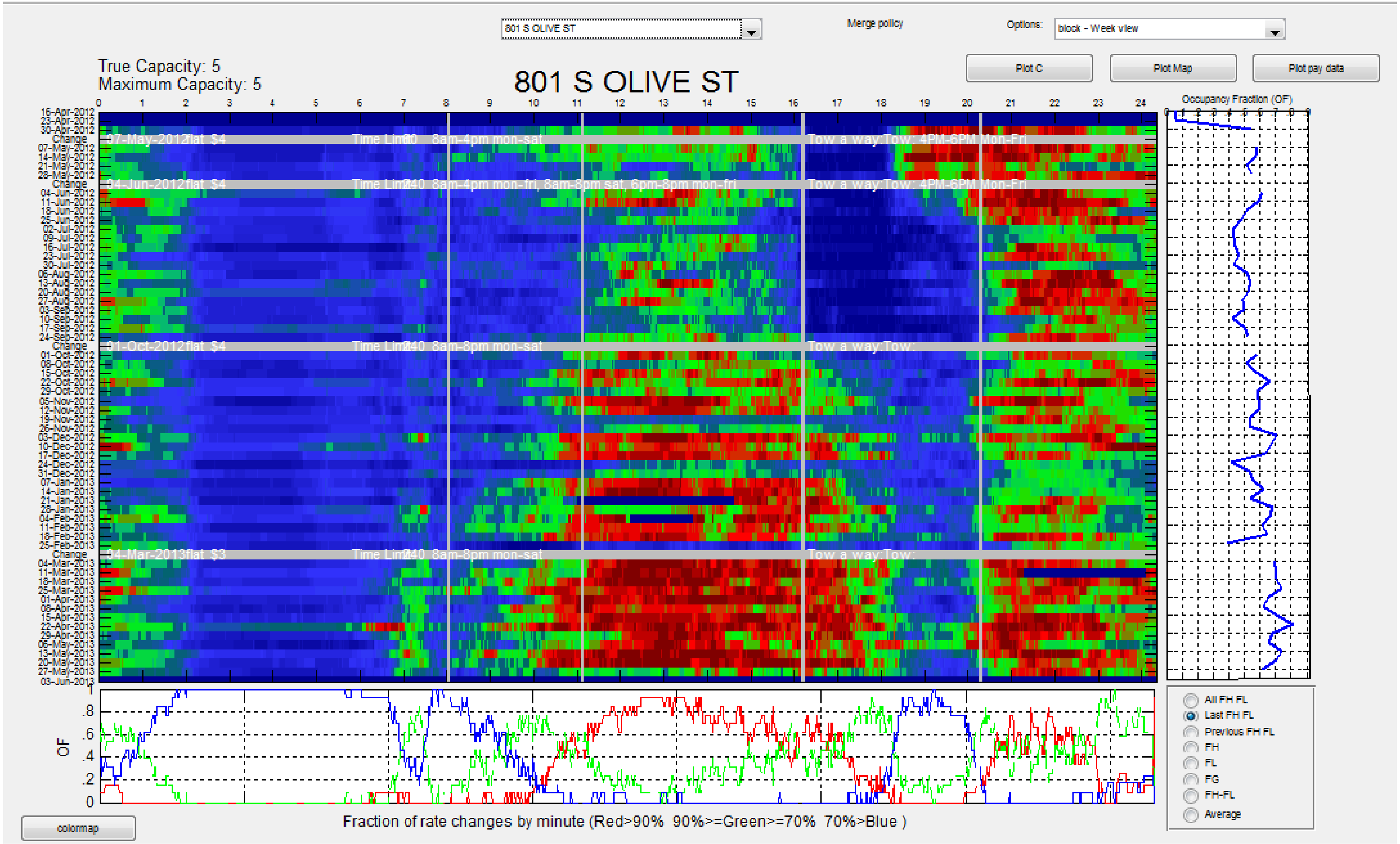


Results of Price Changes: Do People React?



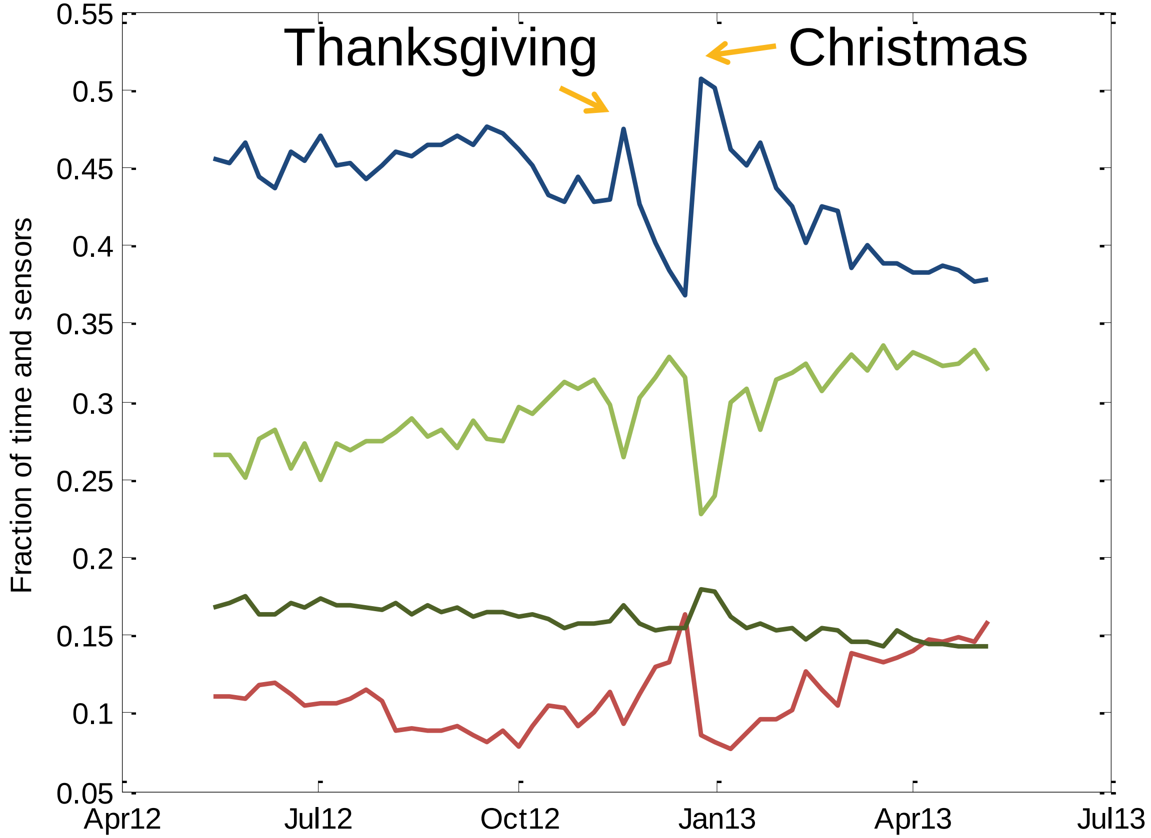
Four situations:

Just-right (Goldilocks)

Not scarce: always enough parking and essentially free

Congested

Under-utilized, yet non-negligible charge



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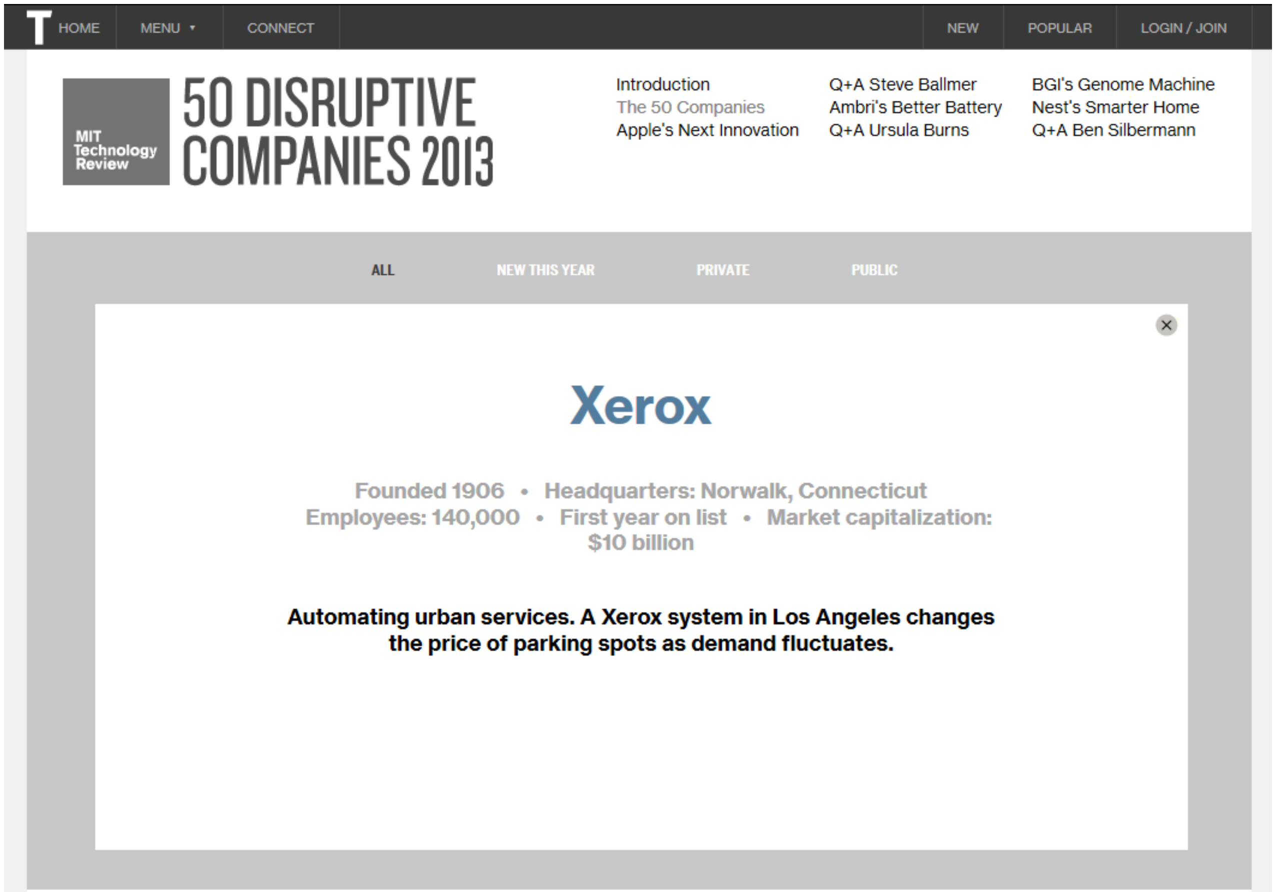

Questions?

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