Choice-based Network Revenue Management under Reviews

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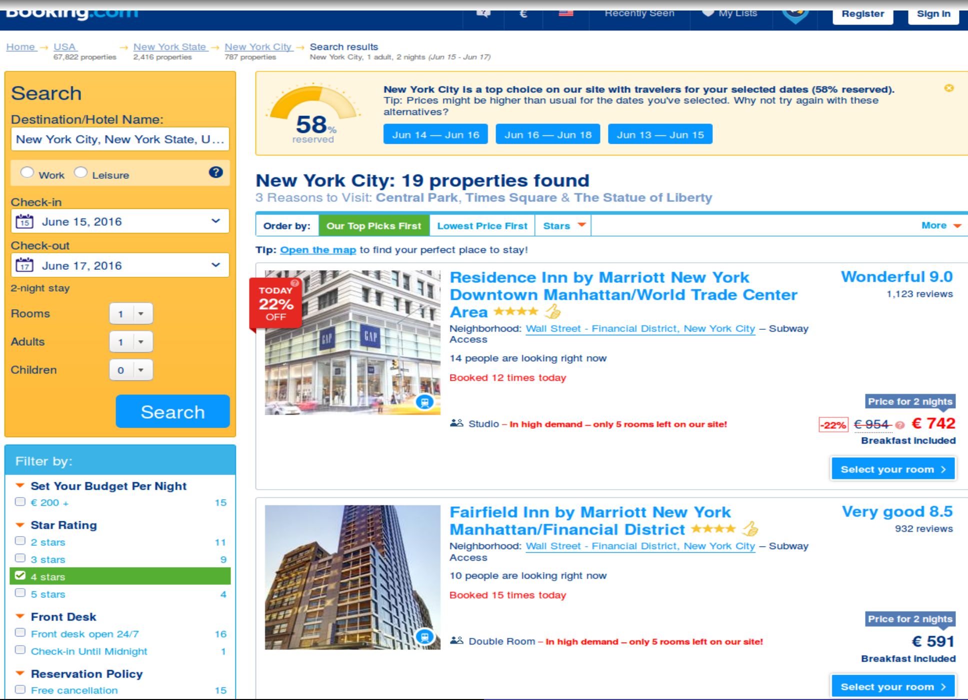
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New York City, 1 adult, 2 nights (Jun 15 - Jun 17)
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June 15, 2016
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2-night stay
Rooms 1
Adults 1
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3 stars 9
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Front Desk
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Check-in Until Midnight 1
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New York City is a top choice on our site with travelers for your selected dates (58% reserved).
Tip: Prices might be higher than usual for the dates you've selected. Why not try again with these alternatives?
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New York City: 19 properties found
3 Reasons to Visit: Central Park, Times Square & The Statue of Liberty
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TODAY 22% OFF
Residence Inn by Marriott New York Downtown Manhattan/World Trade Center Area ★★★★
Neighborhood: Wall Street - Financial District, New York City – Subway Access
14 people are looking right now
Booked 12 times today
Studio – In high demand – only 5 rooms left on our site!
Wonderful 9.0
1,123 reviews
Price for 2 nights
-22% € 954 € 742
Breakfast included
Select your room
Fairfield Inn by Marriott New York Manhattan/Financial District ★★★★
Neighborhood: Wall Street - Financial District, New York City – Subway Access
10 people are looking right now
Booked 15 times today
Double Room – In high demand – only 5 rooms left on our site!
Very good 8.5
932 reviews
Price for 2 nights
€ 591
Breakfast included
Select your room

May 31, 2016

M

Mark
United Kingdom
1 property review

10 "Excellent value for money in a great location"

Leisure trip | Couple | King Studio | Stayed 3 nights

Lifts a little slow at times.

Great location, right next to subway and downtown sights. Staff helpful and friendly. Room the usual small NY standard, but well appointed and laid out. Felt modern and clean. Bed very comfortable. Breakfast was as expected and always well stocked. Gym was small and more for running / cross training etc (a few dumbbells) but perfectly adequate.

Helpful

May 31, 2016

C

Chris
United Kingdom
20 property reviews
2 destination reviews
1 helpful vote

9.2 "Very clean and modern hotel. Friendly. Near WTC"

Leisure trip | Solo traveler | King Studio | Stayed 2 nights

Nothing really. Financial district not really where I want to stay but very near subway. I stayed during memorial weekend and was woken by noise in the corridor (just a group getting back) at 5am. Once they were in their rooms (I think they had two rooms next to each other), I couldn't hear a thing but it all woke me with a start. When there is room (and the rooms here nice and large), I don't know why designers don't put in an internal hall, creating an inner hallway. Hotels that do this are great and it blocks off all the noise from the hallway, people coming in/out, discussing what time for breakfast, knocking on friends doors etc. Anyway not the hotel's fault I stayed during memorial w/e or that I happened to stay next to two rooms who went out partying :-)

Trade-off: Revenue vs Rating

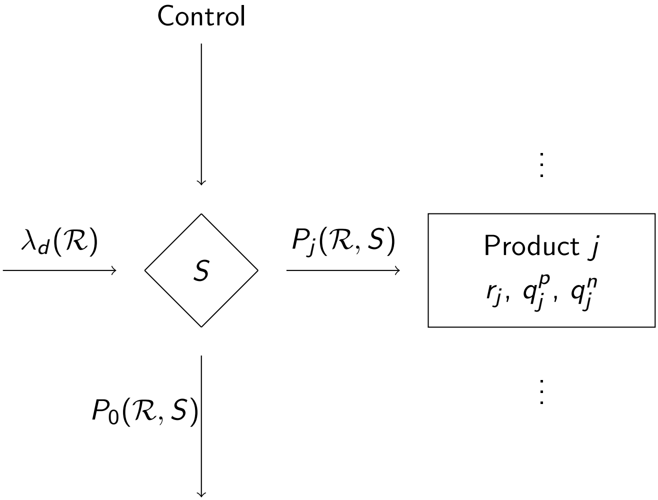
- Customers are highly influenced by (negative) information
- (Negative) reviews influence customers purchasing products
- (Negative) price/quality perception influences customers writing reviews

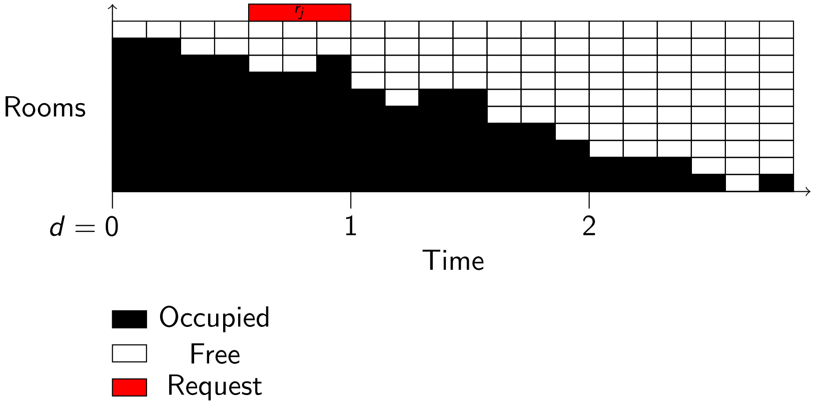
Trade-off: Revenue vs Rating

Goal

Goal: Maximize long-term revenue

- Optimizing revenue might lead to worse ratings and suboptimal revenue


Control
$\lambda_d(\mathcal{R})$
S
$P_j(\mathcal{R}, S)$
Product j
$r_j,\ q_j^p,\ q_j^n$
$P_0(\mathcal{R}, S)$



d: moments when reviews are released

Modelling demand as a function of reviews

Demand in period d:

$$\lambda_d := (\bar{\lambda}_d + \beta^p \tilde{Q}^p_{d-1} + \beta^n \tilde{Q}^p_{d-1}),$$

where

- $\tilde{Q}^p_d = \#$ discounted positive reviews from period d
- $\tilde{Q}^n_d = \#$ discounted negative reviews from period d
- $\beta^p, \beta^n \in \mathbb{R}$ review attribute parameters

Stochastic Problem Formulation

The problem statement is given by

$$\max_{\pi \in \Pi} E[\int_0^T r^\top N(S_\pi(t))dt] \qquad \text{expected revenue}$$

$$\text{s.t.} \int_0^T AN(S_\pi(t)) \leq C, \qquad \text{capacity constraint}$$

$$S_\pi(t) \subset N,$$

where

Π	policy space
$N(S_\pi(t)) \in \mathbb{N}^n$	stochastic process of the vector of purchases at time t under policy π
$S_\pi(t) \subset N$	offer set corresponding to π
$A = (a_{ij})$	resource consumption matrix
$C \in \mathbb{N}^m$	resource capacity vector
$r \in \mathbb{N}^n$	reward vector

Stochastic Problem: Limitations

- High dimensional state space (resources and reviews)
- Large number of products and resources

Solution $\rightarrow$ deterministic demand and reviews

Deterministic Problem Formulation (CRLP)

The choice-based review linear program (CRLP) is given by

$$\max_{\substack{x(S,d):\\ S\subset N, 1\le d\le D}} \sum_{d=1}^{D} \sum_{S\subset N} x(S,d) \sum_{j\in S} P_j(S) r_j$$

$$\text{s.t.} \sum_{d=1}^{D} \sum_{S\subset N} x(S,d) A P(S) \le C,$$

$$\sum_{S\subset N} x(S,d) \le \left(\tilde{\lambda}_d + \sum_{S\subset N} \sum_{d'=1}^{d-1} x(S,d') \mu(S,d,d') \right)^{+}.$$

$x(S,d)$	arrivals when S is offered in period d (decision variables)
$\mu(S,d,d')$	impact of arrivals from period d' when set S is offered on demand in period d

Analytical Results

Proposition 1: Upper bound

$V^{\text{CRLP}} \geq V^*$

Proposition 2: asymptotic optimality

$$\lim_{k\to\infty} \frac{1}{k} V_k^* = \lim_{k\to\infty} \frac{1}{k} V_k^{\text{CRLP}} = V^{\text{CRLP}}.$$

V^{CRLP}	optimal revenue from CRLP
V^*	optimal expected revenue from stochastic problem
V_k^{CRLP}	revenue for k-scaled CRLP
V_k^*	revenue for k-scaled stochastic problem

Solution Methods

CRLP

Offer set S during period d according to $x(S, d)$

Robust CRLP

Motivation: outcome of reviews is uncertain, but impacts future demand

Robust CRLP

Consider demand constraint of CRLP:

$$\sum_{S \subset N} x(S,d) \leq \left(\tilde{\lambda}_d + \sum_{S \subset N} \sum_{d'=1}^{d-1} x(S,d') \mu(S,d,d') \right)^+ .$$

Assume uncertainty in $\mu(S,d,d')$:

$$\mu(S,d,d') = \bar{\mu}(S,d,d') + \zeta(S,d,d'),$$

where $\zeta \in Z$, with Z an uncertainty region of ζ.

Consider an adaptation of box/interval uncertainty:

$$Z = \left\{ \zeta \,\middle|\, |\zeta(S,d,d')| \leq \rho(S,d,d') \right\},$$

with $\rho(S,d,d') > 0$. The constraint can be rewritten to:

$$\sum_{S \subset N} x(S,d) \leq \left(\tilde{\lambda}_d + \sum_{S \subset N} \sum_{d'=1}^{d-1} x(S,d') \left[\bar{\mu}(S,d,d') - \rho(S,d,d') \right] \right)^+ .$$

Robust CRLP

Upside:

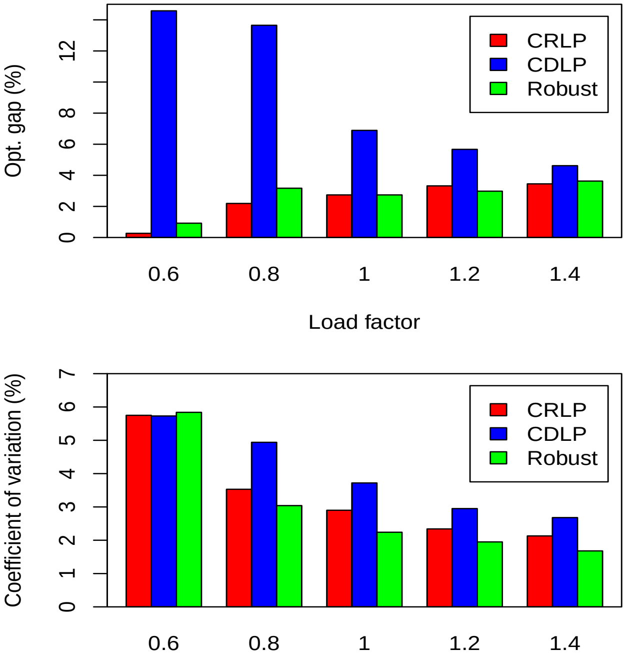
- Leads to tractable MILP (no extra constraints)
- $\rho(S, d, d')$ can be set relatively to the nominal value $\bar{\mu}(S, d, d')$
- (With box uncertainty $\rho(S, d, d') = \rho$, independent from S, d, and d')

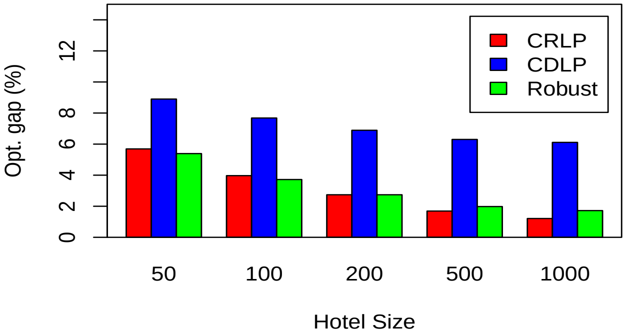
Downside:

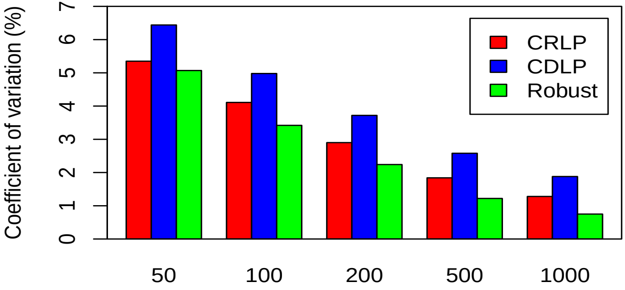
- Conservative

Numerics

- Compare strategies from CRLP, CDLP (benchmark), and Robust CRLP
- Simulate to get expected revenue μ and standard deviation σ
- Optimality gap to measure **expected revenue**
- Coefficient of variation ($c_v = \sigma/\mu$) to measure **robustness**


CRLP
CDLP
Robust
Opt. gap (%)
0
2
4
6
8
12
0.6
0.8
1
1.2
1.4
Load factor
CRLP
CDLP
Robust
Coefficient of variation (%)
0
1
2
3
4
5
6
7
0.6
0.8
1
1.2
1.4


CRLP
CDLP
Robust
Opt. gap (%)
0
2
4
6
8
12
50
100
200
500
1000
Hotel Size


CRLP
CDLP
Robust
Coefficient of variation (%)
0
1
2
3
4
5
6
7
50
100
200
500
1000