INDEX: a status report

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Motivation

Internet use currently has zero marginal cost for use
Result: congestion (see next slide)
Internet currently uses one quality of service (QoS)
Differential quality of service requires differential pricing

Research on QoS
How to engineer QoS: a lot of work
What QoS costs: a little work
How users value QoS: nothing
Goal of INDEX project: measure how users value QoS
Modem use by day and user

![Graph showing modem use by day and user](image-url)
Information about INDEX

INDEX = Internet DEmand eXperiment

Web page: http://www.index.berkeley.edu

Support: Cisco Systems, Pacific Bell, Hewlett Packard, and National Science Foundation.
What is our goal?

Goal: Measure how much users are willing to pay for Internet Quality of Service (QoS).

Dimensions of QoS
- bandwidth (symmetric and asymmetric)
- volume
- congestion
- delay to connect
- etc.
How do we do it?

• Give 150 Berkeley people "free" ISDN service
  hardware and setup costs are free
  we cover PacBell’s monthly charges
• Offer them different QoS for different prices
• Simulate the QoS
  same QoS choices for several weeks
  different prices each week

• Note: real money, simulated service
Interface for INDEX: settings

- **Inactivity Timer**
  - Current: 0
  - Limit: 60
  - Enabled: unchecked

- **Spending**
  - This session (in dollars): $0.87
  - Limit: 0.00
  - Enabled: unchecked
  - Today (in dollars): $2.96
  - Limit: 5.00
  - Enabled: unchecked
  - This month (in dollars): $2.96
  - Limit: 35.00
  - Enabled: unchecked

- Connection Status: Connected - 96kbps
- Today: $2.96
Interface: experiment

Traffic Volume/Capacity-Based Charges

This experiment will end at 30-Nov-98 3:00:52 AM PST

This experiment is intended to measure how you value different Internet access speeds. You are offered speeds between 8kbps and 128kbps. Each access speed will have a traffic-based volume charge AND a time-based capacity charge.

Connection Status
Connected - 128kbps

Session
$0.08
Interface: pricing

![INDEX Project “Control Center”](image)

These prices are valid until 30-Nov-98 3:00:52 AM PST

<table>
<thead>
<tr>
<th>Service</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 kbps</td>
<td>0.0¢/min+0.0¢/mB</td>
</tr>
<tr>
<td>16 kbps</td>
<td>0.1¢/min+4.2¢/mB</td>
</tr>
<tr>
<td>32 kbps</td>
<td>0.2¢/min+4.2¢/mB</td>
</tr>
<tr>
<td>64 kbps</td>
<td>1.0¢/min+4.2¢/mB</td>
</tr>
<tr>
<td>96 kbps</td>
<td>2.0¢/min+4.2¢/mB</td>
</tr>
<tr>
<td>128 kbps</td>
<td>2.1¢/min+4.2¢/mB</td>
</tr>
</tbody>
</table>

Connection Status: Connected - 128kbps

Session: $0.08
Interface: choices

![Image of interface with options: 8 kbps (0.0¢/min+0.0¢/mB), 64 kbps (1.0¢/min+4.2¢/mB), 16 kbps (0.1¢/min+4.2¢/mB), 96 kbps (2.0¢/min+4.2¢/mB), 32 kbps (0.2¢/min+4.2¢/mB), 128 kbps (2.1¢/min+4.2¢/mB).]
Interface: asymmetric BW
Interface: volume pricing
## Interface: billing

<table>
<thead>
<tr>
<th>Date</th>
<th>Service Type</th>
<th>Start Time</th>
<th>End Time</th>
<th>Usage</th>
<th>Data Transfer</th>
<th>Billing</th>
</tr>
</thead>
<tbody>
<tr>
<td>09/15/1998</td>
<td>128kbps</td>
<td>23:14:08-23:13:22</td>
<td></td>
<td>0.000</td>
<td>0.001</td>
<td>0.0000</td>
</tr>
<tr>
<td>09/15/1998</td>
<td>128kbps</td>
<td>23:14:28-23:14:38</td>
<td></td>
<td>0.000</td>
<td>0.001</td>
<td>0.0000</td>
</tr>
<tr>
<td>09/15/1998</td>
<td>128kbps</td>
<td>23:20:20-09/16 00:08:15</td>
<td></td>
<td>0.152</td>
<td>0.001</td>
<td>0.0002</td>
</tr>
<tr>
<td>09/16/1998</td>
<td>128kbps</td>
<td>12:58:38-13:07:00</td>
<td></td>
<td>8.35</td>
<td>0.008</td>
<td>0.0668</td>
</tr>
<tr>
<td>09/16/1998</td>
<td>128kbps</td>
<td>13:09:51-13:09:57</td>
<td></td>
<td>0.10</td>
<td>0.008</td>
<td>0.0008</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.000</td>
<td>0.0000</td>
</tr>
</tbody>
</table>
Where we are

Started providing service April 1, 1998
have about 70 subjects
subjects proceed through experiments asynchronously
Have run
symmetric bandwidth
asymmetric bandwidth
volume pricing
bandwidth + volume mixture (predetermined + self-selected)
pay upfront for flat pricing
Symmetric bandwidth

Usage overall:

Note: 8 kbs is free
Scatter plots

16 Kbps

32 Kbs

price

1000 2000 3000 4000 u16

5000 10000 15000 20000 25000 u32

16 Kbps

32 Kbs
Scatter plots, continued

- **96 Kbs**
- **64 Kbs**
- **128 Kbs**
Demand estimates

**Reduced form:** estimate demand as a function of price
amount consumed = function of prices and individual characteristics

**Structural:** estimate parameters of utility function
choice of bandwidth depends on value of time, urgency, etc. as well as price and characteristics

First look at reduced form, then examine some options for structural estimates
Log Regressions

\[ u_{128} = -2.0 p_{128} + 0.80 p_{96} + 0.25 p_{64} - 0.02 p_{32} - 0.16 p_{16} \]
\[ u_{96} = +1.7 p_{128} - 3.1 p_{96} + 0.43 p_{64} + 0.19 p_{32} + 0.18 p_{16} \]
\[ u_{64} = +0.77 p_{128} + 1.8 p_{96} - 2.9 p_{64} + 0.59 p_{32} + 0.21 p_{16} \]
\[ u_{32} = +0.81 p_{128} - 1.0 p_{96} + 1.0 p_{64} - 1.4 p_{32} + 0.15 p_{16} \]
\[ u_{16} = +0.2 p_{128} - 0.29 p_{96} + 0.04 p_{64} + 1.2 p_{32} - 1.3 p_{16} \]

Red = negative own price effect
Light = not statistically significant

Lesson: large negative own price effect, positive cross price effect
How good is the fit?

\[
\begin{array}{ccc}
\text{ISE} & \text{no ISE} \\
\hline
u128 & .95 & .11 \\
u96  & .93 & .25 \\
u64  & .92 & .18 \\
u32  & .95 & .14 \\
u16  & .90 & .17 \\
\end{array}
\]

ISE = "individual specific effect"; interpretation
Conclusion: very good fits!
Structural estimates

Notation
- \( b = \text{bandwidth chosen} \)
- \( x = \text{bits transferred} \)
- \( t = \text{time at bandwidth } b = \frac{x}{b} \)
- \( p(b) = \text{price of bandwidth } b \)

Utility
- \( u(x) - [c+p(b)]t \)
- \( c \) is value of time; varies with circumstances
- \( f(c) \) is probability distribution of \( c \)
Let \((x,b^*)\) be choice. Optimization requires:

\[
u(x) - [c + p(b^*)]\frac{x}{b^*} \geq u(x) - [c + p(b)]\frac{x}{b} \quad \text{for all } b.
\]

Rearrange to find

\[
\min_{b^* < b} \frac{p(b^*)b - p(b)b^*}{b^* - b} \geq c \geq \max_{b^* > b} \frac{p(b^*)b - p(b)b^*}{b^* - b}
\]

Note that this gives upper and lower bounds on cost of time.
Plot $K(c) = [c + p(b_i)] \cdot (1/b_i)$ for $i = 1,\ldots,n$

Observe $(c_U^i, c_L^i, f^i)$ for $i = 1,\ldots,n$
Histograms for one user

![Histograms for one user](image_url)
Can calculate average time cost for each individual using these frequency distributions.

Table shows number of subject with average estimated time cost that falls in indicated range:

<table>
<thead>
<tr>
<th>Range</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper bound</td>
<td>39</td>
<td>8</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Lower bound</td>
<td>63</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>47</td>
<td>7</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Who has high WTP?

![Est. Time Cost vs Occupation Plot]

- Occupation: Prof, Tech, Admin, Student
- Est. Time Cost: 2, 4, 6, 8
Average cost of time

Very low WTP for time (= 1/2 cent per minute)
  • very small charges induce large changes in behavior
  • lot of low-value traffic out there
  • admin/technical have highest WTP

WTP for population as a whole
  \( c_{\text{LowMean}} = 0.02 \)
  \( c_{\text{UpMean}} = 0.40 \)
  \( c_{\text{LowStd}} = 0.07 \)
  \( c_{\text{UpStd}} = 1.11 \)
Suppose frequencies drawn from prob distribution $p(c, \beta)$
Find distribution that is close to all the frequencies
Closeness = Kullback-Leibler entropy measure, $\Sigma f \log p$

$$\max_{\beta} \sum_{i=1}^{n} f_i \log \int_{c_L}^{c_U} p(x, \beta) \, dx$$
Truncated Normal

$\mu = .487, \sigma = .32$

mean = .52

Graph showing a truncated normal distribution with mean .52 and parameters $\mu = .487$ and $\sigma = .32$. The graph is truncated at the lower end.
µ = .48, σ = .32
max entropy

µ = .42, σ = .25
min SSR
What about population as a whole?

cLowMean = 0.02, cUpMean = 0.40
cLowStd = 0.07, cUpStd = 1.11

Estimated parameters: $\mu = -0.16$, $\sigma = 0.64$, mean time cost = 0.18
Why such a low WTP?

Possible explanations

1. Our population is not representative
can look at demographics, e.g., income effects
2. We only get lower bound on WTP for 128 kbs
   but this is only about 1/6 of use
3. We can’t control QoS outside of Berkeley network
   high bandwidth isn’t worth much if congestion is elsewhere
4. We can only measure value of *existing* applications
Volume experiments

Two bandwidths
  8 Kbs for free
  128 Kbs for money
Price volume downloaded
  prices range from 1 to 20 cents per megabyte
  monthly expenditures similar in bandwidth and volume experiments
Scatterplot
Log Regressions

no ISE: $u_{128} = -0.29 \; p_{128}$ \hspace{1cm} $R^2 = 0.02$
ISE: $u_{128} = -0.24 \; p_{128}$ \hspace{1cm} $R^2 = 1.00$

Interesting finding:
amount transmitted is not sensitive to price
entire effect is individual-specific effect

Why? Probably choice offered is too extreme...
What’s next?

Current experiment: pay flat fee on Sunday to opt out of metered pricing
Move to ADSL or cable modem?
What are you interested in?