Transportation Revenue Forecasting: Theory and Models

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1.201 / 11.545 / ESD.210
Transportation Systems Analysis: Demand & Economics

Fall 2008

Overview

- Increasing reliance on private sector financing of transportation projects (particularly toll roads) has emphasized the importance of accurate revenue forecasting
- Main factors of revenue forecasting:
  - Pricing/tolling strategy
  - Travel demand forecasting
  - Traffic assignment

Outline

- **Review Basic Pricing Concepts**
  - Public Sector Pricing
  - Private Sector Pricing
- Revenue Forecasting
  - Forecasting Accuracy
  - Sources of Uncertainty
- Enhanced Methods
- Conclusion

Review of Public Sector Pricing

- Maximize welfare
- Marginal cost pricing
- Under constraints
  - – Cost recovery: Ramsey pricing
  - – Distortions: second-best pricing

Review of Private Sector Pricing

- Maximize profit or revenue
- Perfectly competitive market
  - Price close to marginal cost
- Less competitive market
  - Price discrimination

Outline

- Review Basic Pricing Concepts
- **Revenue Forecasting**
  - Forecasting Accuracy
  - Sources of Uncertainty
- Enhanced Methods
- Conclusion

Revenue Forecasting

- Revenue forecasting is essential for assessing financial feasibility and project approval
- Here we focus on toll roads and toll bridges

Forecasting Accuracy

- Few examples where actual revenue exceeded the forecast
- Many examples where actual traffic demand and revenue have significantly lagged the forecasts
  - Dulles Greenway in Virginia went into default in 1996, when toll revenues were less than the forecast (20% of the forecast in its first year of operation; and only 35% in its fifth year)

Forecasting Accuracy (cont.)

- 68 case studies during 2003 of traffic forecasting for international toll roads
- Ratio of actual/forecast traffic volumes follows a normal distribution with average 0.74 and standard deviation 0.26

Image removed due to copyright issues.

Source: Bain, R. and Plantagie, T.W. (2003), *Traffic Forecasting Risk: Study Update 2003*, Standard & Poor's RatingsDirect, the McGraw-Hill Companies, New York, [Online], May 2008, Available at: http://www.people.hbs.edu/besty/projfinportal/S&P_Traffic_Update.pdf.

Forecasting Accuracy (cont.)

Examples: Actual revenue as percentage of forecast

Facility	Year of opening	Year 1	Year 2	Year 3	Year 4	Year 5
Florida's Turnpike Enterprise/ Sawgrass Expressway	1986	17.8%	23.4%	32.0%	37.1%	38.4%
Orlando-Orange Expressway Authority/Central Florida Greenway North Segment	1989	96.8%	85.7%	81.4%	69.6%	77.1%
State Road and Tollway Authority (Georgia)/GA 400	1993	117.0%	133.1%	139.8%	145.8%	141.8%
Transportation Corridor Agencies (California)/San Joaquin Hills	1996	31.6%	47.5%	51.5%	52.9%	54.1%
Santa Rosa Bay Bridge Authority (Florida)/Garcon Point Bridge	1999	32.6%	54.8%	50.5%	47.1%	48.7%
Pocahontas Parkway Association (Virginia)/Pocahontas Parkway	2002	41.6%	40.4%	50.8%	NA	NA

Figure by MIT OpenCourseWare.

Source: Kriger, D., Shiu, S. and Naylor, S. (2006), *Estimating Toll Road Demand and Revenue*, National Cooperative Highway Research Program Synthesis 364, Transportation Research Board, [Online], May 2008, Availble at: http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_syn_364.pdf.

Sources of Uncertainty

- Revenue forecasting is based on:
  - Travel forecasts: models and assumptions on which the travel forecasts were based, such as economic growth, land use, and changes in traffic patterns
  - The tolling schedule and structure, e.g., by vehicle type
  - The enforcement of toll collection

- Revenue is estimated by multiplying the forecasted traffic volumes by the toll amount, taking into account different toll rates by vehicle type, potential toll evasion, and discounts

Sources of Uncertainty: Modeling

The four-step modeling process is widely used for traffic demand forecasting

- Travel demand models intended for regional planning purpose may not be appropriate for toll roads
- Steady-state forecast does not incorporate the likelihood of traffic fluctuations during economic cycles
- Peak-hour travel characteristics do not represent annual traffic demand, typically required for toll road revenue forecasts
- Limited data on weekend/truck traffic patterns
- Value of time is heterogeneous and difficult to estimate

Sources of Uncertainty: Input Data

- Demographic, socioeconomic and land-use variables, e.g., population, economic growth, employment, and zone definition
- Transportation network
- Travel characteristics, e.g. origin-destination demand, travel cost, traffic counts and speeds, stated preferences data
- Individual value of time or willingness to pay
- Tolling amount and structure

Other Sources of Uncertainty

- Traffic ramp-up period
  - High financial risk during the initial years of operation
  - Traffic volumes may be lower than forecasted as drivers slowly become aware of the toll facility and time saving, or if population or economic growth is less than forecasted
- Event and political effects, e.g. competing roads

Outline

- Review Basic Pricing Concepts
- Revenue Forecasting
- **Enhanced Methods**
  - Activity-based models
  - Travel choice models (eg time, mode, path)
  - Traffic Assignment (simulation & dynamic models)
  - **Models with heterogeneous value of time**
  - **Travel time reliability**
  - **Uncertainty of forecast results …**
- Conclusion

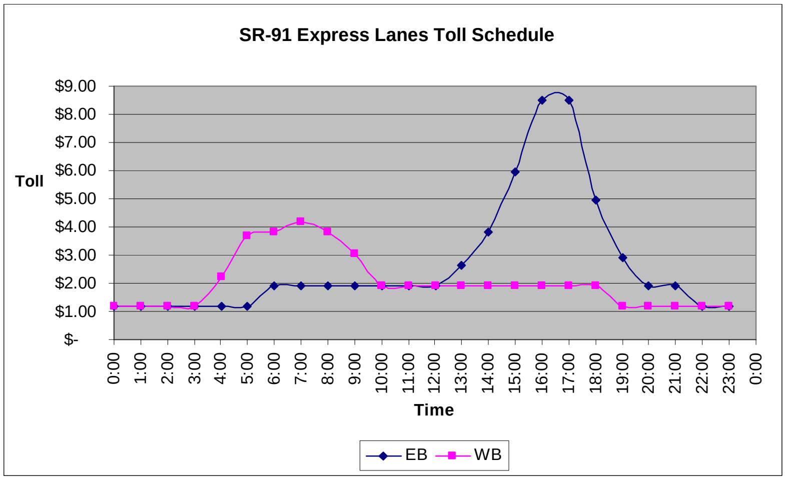
Preference Heterogeneity: An Example

SR-91 in California, USA

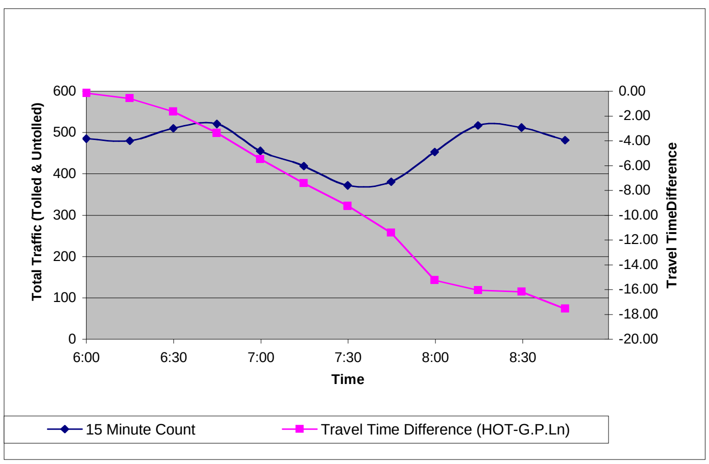
Source: Tian, X., Kulkarni, A. and Jha, M. (2008), Modeling Congestion Pricing, presented at Workshop on Traffic Modeling: Traffic Behavior and Simulation, University of Technology, Graz, Austria

Google map image of California highway SR-91 removed due to copyright restrictions.

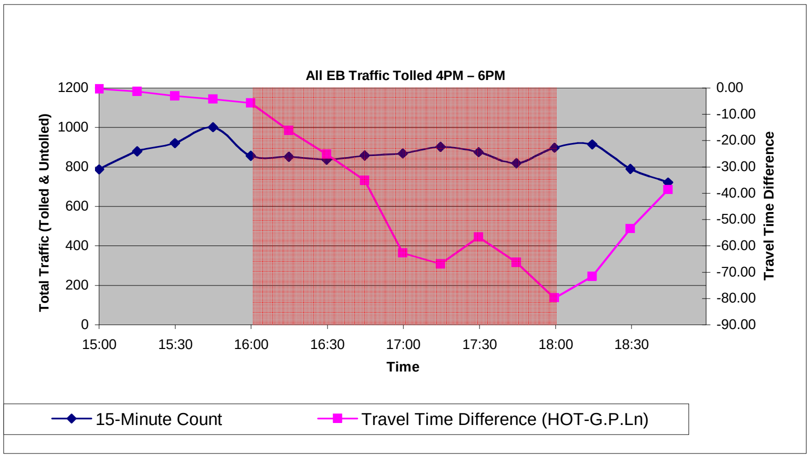
Toll Rates



Travel Time Difference between HOT and General Purpose Lanes: AM



Travel Time Difference between HOT and General Purpose Lanes: PM



Heterogeneous Value of Time

Value of time (VOT) or willingness to pay (WTP) varies by

- Trip purpose
- Time-of-travel
- Travel mode
- Vehicle occupancy
- Congestion levels
- Trip length
- Socio-economic variables, e.g. income, gender, occupation and education level

Heterogeneous Value of Time: Explicit Segmentation

- An explicit segmentation of the corresponding assignment, mode choice and time-of-travel choice models, while assuming a single average VOT within each segment

- Limitations:
  - Requires multi-class assignment with a large number of segments
  - Problematic when different choice dimensions use different segmentation
  - Does not account for within-segment variability

Heterogeneous Value of Time: Explicit Segmentation (cont.)

Example: VOT estimates for toll road users in Montreal model

Gender	Income	Time-of-travel	VOT by purpose		
			Work	Maintenance	Discretionary
Male	Low	Off-peak	$7.30	$4.00	$3.00
		Peak	$10.30	$4.00	$3.00
	High	Off-peak	$10.20	$4.00	$3.00
		Peak	$10.20	$4.00	$3.00
Female	Low	Off-peak	$7.30	$6.40	$6.00
		Peak	$10.30	$6.40	$6.00
	High	Off-peak	$10.60	$7.30	$7.60
		Peak	$10.60	$7.30	$7.60

Source: Vovsha, P., Davidson, W. and Donnelly, R. (2005), 'Making the state of the art the state of the practice: advanced modeling techniques for road pricing', *Expert Forum on Road Pricing and Travel Demand Modeling,* Volpe National Transportation Systems Center, [Online], May 2008, Available at: http://tmip.fhwa.dot.gov/clearinghouse/docs/DOT-OST-P-001-06

Distributed Value of Time

- Probabilistic distribution of VOT instead of deterministic values, with a corresponding adjustment of the structure of the assignment, mode choice, and time-of-travel choice models
- Latent Class Choice Model
  - Discrete distribution of VOT
  - Gopinath, D.A. and Ben-Akiva, M. (1997), 'Estimation of randomly distributed value of time', Working paper, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology.
- Random Coefficient Logit Model
  - Continuous distribution of VOT
  - Coefficients for travel time and travel cost, or their ratio (VOT), is assumed to be randomly distributed

Distributed Value of Time (cont.)

Ben-Akiva, M., Bolduc, D. and Bradley, M. (1993), 'Estimation of travel choice models with randomly distributed value of time', *Transportation Research Record*, vol. 1413, pp.88-97.

$$U_i = \mu\left[c_i + \beta' Y_i + \underbrace{\nu}_{\text{Value of time}}\left(t_i + \gamma' Z_i\right)\right] + \varepsilon_i$$

- c_i = travel cost of alternative i
- t_i = travel time of alternative i
- Y_i = vector of additional variables for alternative i (may include interactions with c_i)
- Z_i = vector of additional variables for alternative i , whose coefficients vary proportionally to the time coefficient (may include interactions with t_i)
- ε_i = additive error terms
- μ = scale parameter
- β, γ = unknown parameters

Distributed Value of Time (cont.)

Choice probability for a lognormal distribution of VOT

$$\ln \nu \sim N\left(\omega, \sigma^2\right)$$

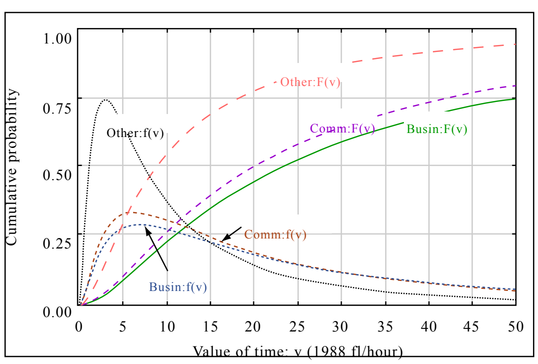
$$P(i) = \frac{1}{\sigma\sqrt{2\pi}} \times \int_0^{\infty} \frac{\exp\{\mu[c_i + \beta' Y_i + \nu(t_i + \gamma' Z_i)]\}}{\sum_{j=1}^{J} \exp\{\mu[c_j + \beta' Y_j + \nu(t_j + \gamma' Z_j)]\}} \times \frac{1}{\nu} \exp\left\{-\frac{1}{2}\left(\frac{\ln \nu - \omega}{\sigma}\right)^2\right\} d\nu$$

– where $\mu, \beta, \gamma, \omega, \sigma$ are the parameters to be estimated simultaneously using maximum likelihood

Distributed Value of Time (cont.)

1988 stated preferences survey in Netherlands

– Asymmetric distribution skewed to the left of the mean, with a minimum value 0 and a tail to the right



Busin: Business
Comm: Commuting

Figure by MIT OpenCourseWare.

Travel Time Reliability

- Motivation
  - Unreliability is one of the primary costs of road congestion
  - There is evidence that people choose toll roads for reliability, even when there are no obvious travel time savings
  - Examples of reliability measures
    - The standard deviation
    - The difference between the 90th percentile and the median
- Value of reliability (VOR)
  - Willingness to pay for reduction in the day-to-day variability of travel time

Modeling Route Choice with Travel Time Reliability

Lam, T.C. and Small, K. (2001), 'The value of time and reliability: measurement from a value pricing experiment', *Transportation Research Part E*, vol. 37, pp. 231-251.

- Revealed preferences survey (1998) of commuters on State Route 91 in Orange County, California
- Travel time measured with loop detectors
- Binary Logit choice model of two parallel routes (either free or with variable toll)

Modeling Route Choice with Travel Time Reliability:

Model Specification

Variables included:

- Travel time median
  - + interaction with a distance function
- Travel time unreliability (difference between the 90th percentile and the median)
  - + interaction with gender
- Travel cost
- Socio-economic variables

Modeling Route Choice with Travel Time Reliability:

Estimating VOR

$$U_{in} = V(t_{in}, \upsilon_{in}, c_{in}, x_{in}) + \varepsilon_{in}$$

$$VOR_n = (\partial V / \partial \upsilon_n) / (\partial V / \partial c_n)$$

$$VOT_n = (\partial V / \partial t_n) / (\partial V / \partial c_n)$$

where:

U_{in} = utility of alternative i for individiual n

t_{in} = travel time

υ_{in} = travel time variability

c_{in} = travel cost

x_{in} = other attributes or characteristics

ε_{in} = error term

Modeling Route Choice with Travel Time Reliability:

Estimation Results

VOT

Trip distance n miles (%)	13 (5%)	27 (25%)	37 (50%)	40 (mean)	50 (75%)	74 (95%)	92 (99%)
VOT ($/h)	5.18	18.45	24.00	25.02	26.31	16.04	-4.05
VOT/mean wage (%)	16%	59%	76%	79%	84%	51%	-13%

VOR

Gender	Male	Female
VOR ($/h)	12.08	29.62
VOR/mean wage (%)	38%	94%

Estimation of Uncertainty

- Uncertainty of Revenue Forecasting is unavoidable
  - Inherent uncertainty in the assumptions about future events and errors in the forecasting procedure
  - Expected value may have large variance and bias
- Probability distribution of forecast results
  - Monte-Carlo simulation
  - Simplified methods

Simplified Method of Estimating the Uncertainty

- Bowman, J.L., Gopinath, D. and Ben-Akiva, M. (2002), 'Estimating the probability distribution of a travel demand forecast', Working paper, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology.
- Requires fewer model runs to estimate elasticities of forecast w.r.t. critical factors affecting uncertainty

Simplified Method of Estimating the Uncertainty (cont.)

- Step 1: Identify independent sources of uncertainty (e.g., economic growth, model error and value of time), and estimate a probability distribution of each source

$$x = (x_1, \ldots, x_k, \ldots x_K)$$
$$x_k^{n_k}, n_k = 1, \ldots, N_k$$
$$p(x_k^{n_k}), n_k = 1, \ldots, N_k \quad \text{s.t.} \quad \sum_{n_k=1}^{N_k} p\left(x_k^{n_k}\right) = 1$$

where x is the vector of sources that induces errors in the forecast; $x_k^{n_k}$ is a discrete outcome of x_k, and $p\left(x_k^{n_k}\right)$ is its corresponding probability

Simplified Method of Estimating the Uncertainty (cont.)

- Step 2: Define a set of scenarios S , and compute the probability of each scenario, $p(s)$, under the assumption of independence of error sources

$$S = \{(x_1^{n_1}, \ldots, x_k^{n_k}, \ldots, x_K^{n_K}); n_k = 1, \ldots, N_k; k = 1, \ldots, K\}$$

$$p(s) = \prod_{k=1}^{K} p(x_k^{n_k(s)}); s \in S$$

- Step 3: Assume travel demand r depends on each source with a constant elasticity e_k

$$r = a \prod_{k=1}^{K} (x_k)^{e_k}$$

and perform model runs to estimate these elasticities

Simplified Method of Estimating the Uncertainty (cont.)

- Step 4: Calculate travel demand for each scenario $r^{(s)}$ based on the predicted value $r^{(p)}$

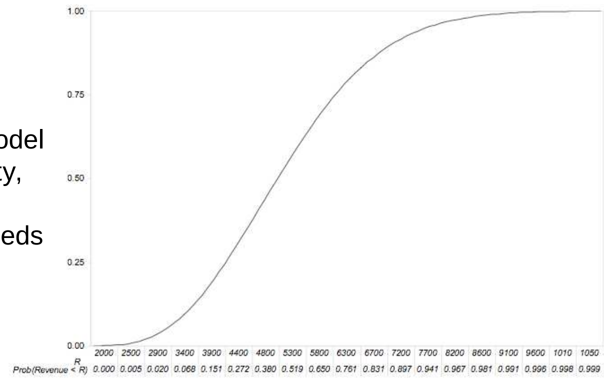
$$r^{(s)} = r^{(p)} \prod_{k=1}^{K} \left(\frac{x_k^{n_k(s)}}{x_k^{n_k(p)}} \right)^{e_k}, s \in S$$

→ All pairs of $r^{(s)}$ and $p(s)$ provide an estimated discrete approximation of $r's$ probability distribution function

Simplified Method of Estimating the Uncertainty (cont.)

Example: Estimated cumulative distribution function of 2001 revenue of a new transit system in a major Asian city

Total 16 sources of uncertainty, such as economic growth, model errors, transit captivity, VOT, measurement errors, operating speeds and headways



Conclusion

- Knowledge of demand and price sensitivities is critical
- Traffic simulation, dynamic traffic assignment, activity-based models, time-of-travel choice models, distributed value of time, and travel time reliability are needed to improve forecasting accuracy
- Uncertainty in revenue forecasts can be estimated

Additional Readings

- Ben-Akiva, M., Bolduc, D. and Bradley, M. (1993), 'Estimation of travel choice models with randomly distributed value of time', *Transportation Research Record*, vol. 1413, pp.88-97.
- Bowman, J.L., Gopinath, D. and Ben-Akiva, M. (2002), 'Estimating the probability distribution of a travel demand forecast', Working paper, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology.
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