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An Options Theoretic Approach to Valuing Travel Unreliability

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SHRP2 Project L11

Presentation Outline

• Why Use Options Theory?
• Basic Concepts and Terms
• Valuing Recurring Unreliability
• Valuing Rare Event Impacts
Why use OPTIONS theory?

- Options theory…
  - Is a branch of financial economics that forms the basis for most methods of valuing uncertainty.
  - Used widely in security valuation, valuing insurance contracts,
  - Allows us to place a singular value on a variable that is not known, but whose statistical distribution is known.

- Classic application of options theory in a financial context is to answer such questions as:
  "How much should I be willing to pay to protect myself from a decline in the value of my shares of IBM?"

- Real-options extends options theory to real, as well as financial matters.
Basic Options Terms

- Different types of options:
  - **Put Option**: Gives me the right to force another party to buy something from me at a specified price [striking price].
  - **Call Option**: Gives me the right to force another party to sell something to me at a specified price.
  - **European Option** can be exercised only at the end of the option agreement.
  - **American Option** can be exercise any time up to and including the end of the option agreement.

- Option Features:
  - The **Premium or Price**, the **Life**, the **Striking or Exercise Price**
How Is Options theory applied to travel time reliability?

- Unreliability means that my commute travel speed has an average value of 30 mph, but is very variable day to day. Thus both my travel speed and travel time is unreliable.

- One might then define the value of unreliability as
  
  “The reduction in average speed that I would be willing to accept in return for elimination of the risk of slower speeds.”

- If the reduction in speed that I would accept in return for reduced variability can be determined, this can be used as a measure of the value of unreliability. It is called the “certainty-equivalent” value of unreliability.

- This value can be monetized by applying a value of time to the travel time associated with the speed reduction.
Valuation of Recurring Unreliability-What do we mean by “Recurring”?

- Recurring unreliability is the variation in travel speeds or times observable over the course of, say, a year of daily speed observations at the same time of day.

- In other words, the stochastic performance of the highway is directly measurable.

- Typically, one observes that:
  - Speed is distributed log-normally, and the log-standard deviation is thus measurable.

- It turns out that these distributional features make it possible to use option valuation formulae to solve for the certainty-equivalent value of unreliability.
  - Specifically, the valuation of recurring unreliability is akin to an insurance policy against declines in speed which, in turn, can be modeled as a European Put Option.
Option value is the decline in average speed a traveler is willing to accept to not suffer speed variability with certainty.

Value of the Option = \( f(V, I, m) \)

where

\( m = f(r, \sigma) \)

and where

- \( V \) = Known speed
- \( I \) = Speed guarantee
- \( r \) = Annualized interest rate
- \( \sigma \) = Variability of \( V \)
Parameters for the Options Valuation are Readily Available

![Graph showing average speed and speed variability over time of day](image-url)
Parameters for the Options Valuation are Readily Available
Since the certainty-equivalent values of the option can be expressed in minutes or hours of delay, the burden of unreliability is monetized by applying the appropriate values of time to these delay measures for each user group.

<table>
<thead>
<tr>
<th>User Group</th>
<th>Volume</th>
<th>Value of Time ($/min)</th>
<th>Certainty-Equivalent Delay (min per mile)</th>
<th>Total Value (per hour per mile)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Occupant Vehicles</td>
<td>5,000</td>
<td>$0.30</td>
<td>0.09</td>
<td>$135.00</td>
</tr>
<tr>
<td>High Occupant Vehicles</td>
<td>1,500</td>
<td>$0.35</td>
<td>0.09</td>
<td>$47.25</td>
</tr>
<tr>
<td>Trucks</td>
<td>750</td>
<td>$0.70</td>
<td>0.09</td>
<td>$47.25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$229.50</strong></td>
</tr>
</tbody>
</table>
Options approach can aid Operations planning

- Using the options theoretic approach to evaluate operations strategies to improve travel time reliability:
  1. Calculate certainty-equivalent of delay for the facility before the operations strategy.
  2. Estimate the impact of operations strategy on travel time distribution (e.g., log-mean and log-standard deviation of speed).
  3. Calculate the certainty-equivalent of delay for the facility with the proposed strategy.

- Proceed using traditional BCA framework such that the value of reliability can be compared to other user benefit categories and the cost of the operations strategy can be compared to the estimated benefits.

- If there is a regular relationship between speed and its variability, the cost of unreliability can be incorporated in volume-delay relationships in a regional model.
### Example of the Scale of Unreliability Effects

<table>
<thead>
<tr>
<th></th>
<th>Selected Facilities</th>
<th>HOT Lanes</th>
<th>Area Charges</th>
<th>Freeway-Only Tolling</th>
<th>Ubiquitous Network Tolling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gross User Travel Savings (Gains in Consumer Surplus)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>User Time</td>
<td>$103</td>
<td>$124</td>
<td>$-2</td>
<td>$833</td>
<td>$1,688</td>
</tr>
<tr>
<td>User Travel Unreliability</td>
<td>$-2</td>
<td>$26</td>
<td>$3</td>
<td>$519</td>
<td>$540</td>
</tr>
<tr>
<td>User Vehicle Operating Costs</td>
<td>$-3</td>
<td>$-7</td>
<td>$0</td>
<td>$21</td>
<td>$50</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>$97</td>
<td>$143</td>
<td>$0</td>
<td>$1,373</td>
<td>$2,278</td>
</tr>
<tr>
<td><strong>User Toll Gains in Consumer Surplus and Agency Gains in Revenues and Costs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>User Toll Gains in Consumer Surplus</td>
<td>$-91</td>
<td>$-75</td>
<td>$-124</td>
<td>$-2,018</td>
<td>$-6,608</td>
</tr>
<tr>
<td>Agency Gains in Revenues</td>
<td>$89</td>
<td>$75</td>
<td>$103</td>
<td>$1,926</td>
<td>$6,110</td>
</tr>
<tr>
<td>Agency Gains in Amortized Facility Costs</td>
<td>$-51</td>
<td>$-44</td>
<td>$0</td>
<td>$-156</td>
<td>$-165</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td>$-53</td>
<td>$-44</td>
<td>$-21</td>
<td>$-248</td>
<td>$-664</td>
</tr>
<tr>
<td><strong>Net Transportation Benefits</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net Benefits (Puget Sound)</td>
<td>$44</td>
<td>$99</td>
<td>$-20</td>
<td>$1,125</td>
<td>$1,614</td>
</tr>
<tr>
<td>Net Benefits (Portland Metro, est.)</td>
<td>$24</td>
<td>$55</td>
<td>$-11</td>
<td>$619</td>
<td>$888</td>
</tr>
</tbody>
</table>

*Figures are estimates.*
Using Options Theory to Evaluate Rare Events

- Rare events include such phenomena as earthquakes, floods, hurricanes, bridge failures, etc.
- Rare events do not occur frequently, but may have catastrophic effects on the transportation system.
- These events are believed to follow non-normal, Extreme Value (EV) distributions such as the Weibull, Frechet and Gumbel distributions.
- Since these events are rare, the simple options theory approach cannot be used to help plan for impacts on the transportation system. Information is only available on the distribution of events, not the transportation system impacts.
Examples of EV Distributions

- Weibull
- Fréchet
- Gumbel
An Approach to Rare-Event Unreliability Mitigation

- Rare-event reliability is an important aspect of transportation system planning:
  
  "How much money should the Bay Area spend to protect its bridges from earthquake risk?"

  "How many hurricane events should a highway be built to survive?"

- In order to answer such questions, it is necessary to model both the processes that generate the rare events, and the processes that generate the scale of impact of the events.

- This requires more complex options modeling embedded in a spending-decision framework.
An EV Evaluation

Formulation

\[ F(V; K, x, \pi, s)_{\text{Gumbel}} \]

where

\[ F(\cdot) = \text{the present discounted value function of the option} \]
\[ V = \text{the present discounted value of the event when it occurs} \]
\[ K = \text{the present discounted value of the cost investing to mitigate impacts} \]
\[ x = \text{the number of events, } x > \mu \]
\[ \pi = \text{the mean of the process that generates } V, \pi > 0 \]
\[ s = \text{the standard deviation of the process that generates } V, s > 0 \]
\[ V^* = \text{the value of the event below which it is worth continuing to wait to invest } K \]
Summary

• The options theoretic approach is a promising method of measuring both recurring reliability and extreme event reliability issues in transportation.

• As a practical matter, the recurring unreliability applications are easier to deploy.

• This is especially true in settings where there is comprehensive instrumentation of roadways to measure vehicle volumes and speeds.

• It is especially useful in settings where stated preference or revealed preference information about the value of reliability is lacking.
An Options Theoretic Approach

Questions & Discussion