Asymmetric Interactions, and the Role of Incentives and Pricing: Implications for Network Modeling

José Holguín-Veras, Ph.D., P.E.
William H. Hart Professor
Director of the Center for Infrastructure, Transportation, and the Environment
jhv@rpi.edu

Asymmetric (power) interactions

- Symmetric case:
  - It does not matter which player is impacted with an cost/incentive because players transfer them

- Asymmetric case:
  - One player has more power than the other
  - Under some market conditions, dominated player cannot pass (some) costs to dominant player; dominant player could impose its will on the other
    - Pricing schemes that target the dominated player are doomed to fail
  - The key is to change the behavior of dominant agent
Carrier centered policies, e.g. freight pricing

**Legend:**
- Decision about off-hour deliveries
- Price signals
- External stimuli

(This must happen for almost all receivers in the tour)

**Examples**

- In urban freight transportation:
  - The interactions between receivers (dominant) and carriers (dominated) that determine delivery times
  - We’ll discuss this in detail

- In passenger transportation:
  - The interactions between employer (dominant) and employees (dominated) that determine preferred arrival time, and time of arrival flexibility
  - We’ll fly over work on in progress by Wilfredo Yushimito, Jeff Ban, and JHV
The urban freight demand case

Part of a project that has been, at times...

- A science mystery
- A political thriller
- A melodrama
- A comedy
- A Greek tragedy
- A good drama with a happy ending...
We all know that...

- If prices go up, transportation demand goes down
- In freight road pricing:
  - Tolls are imposed on truck traffic
  - Carriers pass the toll to the receivers / shippers
  - Receivers / shippers will react by moving their operations to the off peak hours
- Right?
- Not quite..... Reality is more complex than we think
- The experience of the Port Authority of New York and New Jersey’s Time of Day Pricing Initiative (2001) provides great insight

Observed Behavioral Changes *(Holguín-Veras et al. 2006)*

Legend:
- Increasing impact on receivers
- Changes in Facility Usage and Cost Transfers
- Productivity Increases and Changes in Facility Usage
- Only the carrier is impacted
- Carrier and receiver are impacted
- Only the receiver is impacted

![Diagram showing observed behavioral changes with arrows indicating productivity increases, facility usage, and cost transfers.](image-url)
Observed Behavioral Changes (Holguín-Veras et al. 2006)

Legend:
- Increasing impact on receivers

The role of carrier-receiver interactions
The decision about delivery time

- Is made jointly between receivers and carriers
  - 40% by receivers, 38% between receivers and carriers and 22% by carriers
- Let’s take a look at the payoff matrix
  - The first sign represents the impact on carrier and the second the impact on receiver

<table>
<thead>
<tr>
<th>Carrier</th>
<th>Receiver</th>
<th>Regular hours</th>
<th>Off-hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular hours</td>
<td>(−, +)</td>
<td>(−, −)</td>
<td></td>
</tr>
<tr>
<td>Off-hours</td>
<td>(−, −)</td>
<td>(−, −)</td>
<td></td>
</tr>
</tbody>
</table>

(These are non-feasible solutions)

The key is to provide incentives to receivers so that they prefer OHD!

(This is the solution preferred by most carriers)

The joint (carrier-receiver) behavioral response
Receiver behavior

- Can be assumed to be a monotonic function of an external incentive
  \[ P(R_i \in \Omega_j^O / F) = P(F) \]
  \[ P(R_i \in \Omega_j^O / 0) = P(0) = p_0 \] Base case participation
  \[ P(R_i \in \Omega_j^O / \infty) = P(\infty) = 1 \] All receivers participate if incentive is infinite

- However, the random nature of the response gives rise to random configurations of service areas

Typical random configurations

Base case operations:
\[ A = A^{BC} \]

After receiving an incentive, the receivers will be split in two subsets:
- Regular hour receivers
- Off-hour receivers

Thus creating two delivery networks with two service areas
Single tour carrier under Cordon TOD pricing

- **Base case costs**
  \[ C_j^B = (C_{jF}^B + C_{jH}^B) + c_D^B D^B + e_{jT}^B T^B + S^R \]

- **Mixed case (with regular + off-hour deliveries)**
  \[ C_j^M = \left[ (C_{jF}^R + C_{jH}^R) + (C_{jF}^O + C_{jH}^O) \right] + \left[ e_{jT}^R T^R + e_{jT}^O T^O \right] + S^R \]

- **Necessary condition for carrier to move**
  \[ G_j^M - C_j^M \geq G_j^B - C_j^B \]
  \[ \left[ (C_{jF}^R + C_{jH}^R) + (C_{jF}^O + C_{jH}^O) \right] + \left[ e_{jT}^R T^R + e_{jT}^O T^O \right] \leq \Delta G_j, \text{iff } \delta^O < \delta^B \]

- **Key finding:** The toll surcharge plays no role! (in the mixed case the carrier also pays the surcharge)

---

The paradox of Cordon TOD

- **The results show that in a mixed operation, the toll surcharge plays no role:**
  \[ \left[ (C_{jF}^R + C_{jH}^R) + (C_{jF}^O + C_{jH}^O) \right] + \left[ e_{jT}^R T^R + e_{jT}^O T^O \right] \leq \Delta G_j, \text{iff } \delta^O < \delta^B \]

- **If all receivers switch to the off-hours, the surcharge plays a role!**
  \[ c_{j}^O T^O - c_{jT}^B T^B \Delta G_j, \text{iff } \delta^O = \delta^B \]

- **However, the surcharge is not needed after all!**
- **Why?!** Because in the off-hours the time related cost savings are so large that they provide the incentive needed for the carrier to switch
Impacts on receivers

- So far the discussion has centered on the impacts that the pricing scheme has on the carrier.
- Let’s focus now on the impacts that the pricing scheme has on the receivers.

Legend:
- Decision about off-hour deliveries
- Price signals
- External stimuli

Delivery rates

- In a competitive market, prices equal marginal cost.
- Computing the marginal cost, one could obtain:
  - Cordon time of day pricing:
    
    \[
    m_{j}^{CTD}(N^e) = c_D \frac{\partial D^e}{\partial N^e} + c_T \frac{\partial T^e}{\partial N^e}
    \]
  - Time-distance pricing:
    
    \[
    m_{j,TDP}^e(N^e) = \left( c_D + a_T \right) \frac{\partial D^e}{\partial N^e} + \left( c_T + a_T \right) \frac{\partial T^e}{\partial N^e}
    \]

- Key finding:
  With TDP carriers will be able to transfer costs (explaining ATA’s and other groups’ positions).
Would TDP induce the receivers to switch?

- For this to happen, the toll signal reaching the receivers:
  \[ m_{j,TDP}^R(N^R) = \phi \sqrt{L_{n_j} L_{ov}} \left[ \left( c_D + \frac{c_R^p}{u^R} \right) + \left( \alpha_D^R + \frac{\alpha_R^p}{u^R} \right) \frac{\partial D(N^R)}{\partial N^R} \right] \]

- Must be larger than the receivers’ cost to switch:
  \[ \Delta C_{i,N^R} = m^D \left[ \phi \left( \frac{N^R - 1}{N^R + 1} \right) \sqrt{A_o + \frac{F^o}{N^R}} \right] \]

- This implies:
  \[ \phi \sqrt{A_o} \left( \alpha_D^R + \frac{\alpha_R^p}{u^R} \right) \frac{\partial D(N^R)}{\partial N^R} \geq m^D \left[ \frac{\phi}{u^R} \left( \frac{N^R - 1}{N^R + 1} \right) \sqrt{A_o + \frac{F^o}{N^R}} \right] \]

Tolls must be larger than the ratio of the expected incremental cost of switching to the expected marginal distance traveled.

Minimum time-distance unit tolls

\[ \left( \alpha_D^R + \frac{\alpha_R^p}{u^R} \right) \]

These are humongous tolls! (The current value is about $6/mile)

Implication: TDP could induce a change in very short tours
“Integrative Freight Demand Management in the New York City Metropolitan Area”

---

Interlocking components

- Behavioral/economic components
  - Analyses of most promising industry segments
  - Incentives to receivers of cargo willing to do OHD
- Technology component
  - GPS to assess performance (cell phones, own systems)
- Network modeling component
  - Mesoscale traffic model to assess local impacts
  - Regional model to assess networkwide impacts
- Industry/Agency outreach component
  - To get feedback from all involved
- Small scale pilot test component
  - To assess real life impacts...

JHV aged twenty years
Regular vs. Off-Hour Deliveries (1 of 2)

Regular vs. Off-Hour Deliveries (2 of 2)
Typical results from satisfaction surveys

- Scale: 1= Very favorable, 5= Very unfavorable
- Whole Food Vendors: 1.55
- Participating drivers:
  - Travel speeds = 1.33
  - Congestion = 1.11
  - Parking = 1.11
  - Stress levels = 1.11
  - Time to deliver goods = 1.38
  - Time to complete the route = 1.44
  - Driver’s feeling of safety = 1.86
Average service times

More than three times as fast

At the end of the financial incentive...

- Receivers doing staffed OHD:
  - Reverted back to the regular hours
- Receivers doing unassisted OHD:
  - Stayed in the off-hours!
  - Why?
    - Reliability
    - The financial incentive provided allowed to explore OHD (if something went wrong, the incentive would have paid for the costs)
- This shows the potential of unassisted OHD
  - Much lower costs than staffed OHD
  - Same benefits
NYC adopted off-hour deliveries as part of its sustainability strategy
A 2nd USDOT project is going to do a full implementation in NYC
Facts about Commuting: Work/School Trips

- Compulsory trips more often during peak hours:
  - NY/NJ: 87.94% in the AM and 61.83% in PM were To/From Work or other compulsory trips (Holguín-Veras et al., 2005)

- Flexibility (Emmerink and van Beek, 1997)
  - 67% of respondent do not have flexibility at all (work)

- Work arrival flexibility (Holguín-Veras et al., 2005):
  - 67.4% of users who travelled for work determined their time of travel on the basis of their work schedules
  - Cars / Transit:
    - Flexibility on earlier arrival (20.4 / 18.3 minutes)
    - Flexibility on later arrival (12.3 / 9.1 minutes)

Work Trips: Characteristics

- Work Constraints:
  - “Employers are likely to have more discretion than workers in scheduling work hours...Most employees face a Hobson’s choice” (Jones, 1977)

- Flexibility:
  - Departure time decision influenced by work schedule flexibility (Abkowitz, 1981)
  - Flexibility on arrivals or suitable transit choices are a necessary condition for implementing congestion pricing (Emmerink and van Beek, 1997, Holguín-Veras et al., 2005)
Parallel with Off-Hour Deliveries

<table>
<thead>
<tr>
<th>FIRM</th>
<th>STD</th>
<th>SWH</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-,+)</td>
<td>Infeas.</td>
<td></td>
</tr>
<tr>
<td>Infeas.</td>
<td>(+, -)</td>
<td></td>
</tr>
</tbody>
</table>

Firm requires Incentive

<table>
<thead>
<tr>
<th>FIRM</th>
<th>STD</th>
<th>SWH</th>
</tr>
</thead>
<tbody>
<tr>
<td>(+,+)</td>
<td>Infeas.</td>
<td></td>
</tr>
<tr>
<td>Infeas.</td>
<td>(-, -)</td>
<td></td>
</tr>
</tbody>
</table>

Both require Incentive

Overview of Models

- Compute optimal incentive level:
  - Computing economic welfare
  - Modeling Dynamic User Equilibrium
- Computing traffic response for a given incentive
  - For a given incentive, what’s the impact on traffic?
Mathematical Formulation: MPEC w/DUE

\[
\begin{align*}
\text{Min} & \quad \sum_k \left( \beta_0 + \beta_1 k + \beta_2 k^2 \right) \sum_i v_{ik}^t + \theta \sum_i v_{ik}^t - \theta \sum_{i \in E} v_{ik}^t \\
\text{subject to} & \quad \text{Additional cost of the firm due to SWH} \\
& \quad \Phi_s(u, \pi, d) = \left( r_s^t(u) + \sum_{l \in \mathcal{L}_s} \lambda_{s,l}^t(u) \pi_{s,l}^t + [1 - \lambda_{s,l}^t(u)] \pi_{s,l}^t - \pi_{s,l}^t \right) \geq 0, \forall \alpha, s, t \\
& \quad 0 \leq u_{im}^n - \Phi_s(u, \pi, d) \leq \sum_{l \in \mathcal{L}_s} \lambda_{s,l}^t(u) \pi_{s,l}^t + [1 - \lambda_{s,l}^t(u)] \pi_{s,l}^t - \pi_{s,l}^t \geq 0, \forall k, m, i, s \\
& \quad 0 \leq d_{im}^n \leq \left( \pi_{im}^n + \phi - (k_m - k_i) \right) - \mu_{im}^n \geq 0, \forall k, m, i, s \\
& \quad 0 \leq \eta - \alpha_s (k_m - \sigma - \Pi) \leq \eta - \alpha_s (k_m - \sigma) \geq 0 \\
& \quad 0 \leq \phi - \eta \geq 0 \\
& \quad 0 \leq \mu_{im}^n \leq \sum_k d_{im}^n - d_{im}^n \geq 0 \\
& \quad 0 \leq \pi_{im}^n \leq \Phi_s(u, \pi, d) = \left( \sum_{l \in \mathcal{L}_s} \lambda_{s,l}^t(u) \pi_{s,l}^t + [1 - \lambda_{s,l}^t(u)] \pi_{s,l}^t - \pi_{s,l}^t \right) \geq 0, \forall i, s, i \neq s, k' \\
& \quad \sum_{i} d_{im}^n - Q_m = 0 \\
\end{align*}
\]

Conclusions
Chief conclusion

- A comprehensive consideration of the interactions between the agents that determine time of travel is extremely important because:
  - It allows to identify the incentive/pricing structures needed to enact change
  - It avoids penalizing the dominated agent in the (false) hope that it could change the behavior of dominant player
  - It leads to business friendly policies

Addressing the issues, removes the opposition

- Sample publications praising the OHD project:
  - BLOG Coverage
    - [http://www.theepochtimes.com/n2/content/view/38422/](http://www.theepochtimes.com/n2/content/view/38422/)
Fleets Say They Discovered Time, Cost Bonanza Through New York’s Night-Delivery Experiment

By Michelle Faulkner

New York City officials have released results of a pilot program to test the feasibility of off-hours deliveries. The program, which ran from July 2004 to January 2005, involved 35 participating companies and 19,000 deliveries. The results showed that off-hours deliveries can save time and money for businesses and customers. The program was part of a larger initiative to relieve traffic congestion in the city. The pilot program also revealed that off-hours deliveries can reduce emissions and improve air quality. The city plans to expand the program to include more companies and routes. (See next page.)

Thanks