Intel Logistics

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Agenda

- Problem Description
- Methodology
- Single echelon model
- Multi-echelon model
- Optimal supply rate
- Sensitivity and scenario analysis
- Deliverables and potential value
Client Background

- World’s largest semi-conductor chip manufacturer
- New product – Ultra Low Cost PC (ULPC) chip
- Volume of 700 million targeting emerging markets
- Anticipated revenue per chip is $30-$45
- Focus on supply chain from A/T to OEM site
Problem Description

• ULPC – pressure on margins
  – ASP decreased by ~60%
  – Logistics costs decreased by ~50%

• Intel’s current Supply Chain
  – High inventory holding cost
  – 80% expedited airfreight

• ULPC chip Supply Chain
  – Lower inventory holding cost
  – Lower cost contracted freight

Develop a model to reflect the trade-offs between inventory holding costs and transportation costs.
Objective

Provide intuition and tools to support strategic decisions involved in designing a supply network with two modes of transportation within a single lane.

Key points

• Strategic vs. operational focus
• Regular and expedited transportation
• Single and multi-echelon system
Controlled Wiener Process

- Demand Behavior
  - Average demand rate moves predictably
  - Actual demand varies around average

- Controlled Wiener Process (Brownian Motion)
  - Requires just mean and variance
  - Supported by functional central limit theorems
  - New product – no data available
Single Echelon Inventory Model

- All regional demand served from regional DC
- Negotiated contracts for regular transport
  - Eg. Standard air freight (4-5 day lead time) via global freight forwarders
- Option to expedite
  - Eg. Expedited air freight (1-2 day lead time) via integrators such as UPS, DHL and global freight forwarders

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Inventory Model

\[ X(T) = X(0) + \int_0^T [\mu(t) - \lambda(t)] dt + \sigma W(T) + A(T) - R(T) \]

- \( X(T) \) – Inventory level at time \( T \)
- \( \mu(t) \) – Supply level
- \( \lambda(t) \) – Demand level
- \( \sigma \) – Standard deviation of netput
- \( W(t) \) – Standard Wiener process
- \( a(t) \) – Expedited shipments at time \( t \)
- \( r(t) \) – Curtailed shipments at time \( t \)

\[ A(T) = \int_0^T a(t) dt \quad R(T) = \int_0^T r(t) dt \]
Inventory Model – Basic Adjoint Relationship

\[ X(T) = X(0) + \int_0^T [\mu(t) - \lambda(t)]dt + \sigma W(T) + A(T) - R(T) \]

Choose appropriate test functions \( f(x) \)

Gives us performance metrics

\( E(X) \) - Long run expected inventory level

\( \tilde{A} \) - Long run average expedite rate

\( \tilde{R} \) - Long run average curtailed rate
Inventory Model – Performance Metrics

Test functions:

\[
f(X) = \begin{cases} 
X, & X^2, & e^{\frac{-2(\mu - \lambda)X}{\sigma^2}} 
\end{cases}
\]

<table>
<thead>
<tr>
<th>Performance Metric</th>
<th>(\mu \neq \lambda)</th>
<th>(\mu = \lambda)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(E[X])</td>
<td>(-\sigma^2 + e^{\frac{2M(\mu - \lambda)}{\sigma^2}}(2M(\mu - \lambda) + \sigma^2))</td>
<td>(\frac{M}{2})</td>
</tr>
<tr>
<td>(\tilde{A})</td>
<td>(\frac{\mu - \lambda}{\frac{2M(\mu - \lambda)}{\sigma^2}}) (-1)</td>
<td>(\frac{\sigma^2}{2M})</td>
</tr>
<tr>
<td>(\tilde{R})</td>
<td>(\frac{2M(\mu - \lambda)}{\sigma^2} - e^{\frac{2M(\mu - \lambda)}{\sigma^2}}(\mu - \lambda))</td>
<td>(\frac{\sigma^2}{2M})</td>
</tr>
</tbody>
</table>
Multi-Echelon Inventory Model

- A/T → RDC → Local Hubs → Customers (OEM/CDMs)
- Inventory held at RDC as well as local hubs.
- Option to expedite between:
  - A/T → RDC
  - RDC → Local hubs
Inventory Model - Costs

Total Cost / time = $E(X).h + \mu.C_c + \tilde{A}.C_e + \tilde{R}.C_d + P$

$C_c = \text{Cost of contract freight}$

$C_e = \text{Cost of expedited freight}$

$C_d = \text{Cost of delayed freight}$

$P = \text{Cost of pipeline inventory / time}$

$h = \text{Holding cost / time}$

Total cost calculated from inventory levels and transportation volumes.
Multi-Echelon Inventory Model - Equations

\( n \) Local Hubs served by an RDC whose inventory is modeled as

\[
Z(T) = Z(0) + \int_0^T \left[ \mu_0(t) - \sum_i \lambda_i(t) \right] dt + \sum_i \sigma_i W_i(T) + A_0(T) - R_0(T)
\]

Consequently, Basic Adjoint Relationship is

\[
E \left[ f'(Z)(\mu - \lambda_0) + \frac{\sigma^2}{2} [f''(Z)] \right] + (f'(0) . \tilde{A}_0) - (f'(M) . \tilde{R}_0) = 0
\]

Where

\[
\sum_{i=1}^n \sigma_i^2 = \sigma^2 \quad \sum_{i=1}^n \mu_i = \mu
\]

- BAR similar to single echelon \( \Rightarrow \) same 3 test functions for performance metrics
## Performance Model

- Single echelon
- Specific lane, geography and demand scenario
- Calculates performance metrics and costs

<table>
<thead>
<tr>
<th>Metric</th>
<th>General Case</th>
<th>When ( \lambda = \mu )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Contract Supply Rate (( \mu ))</td>
<td>829,052 chips/week</td>
<td>1,153,846 chips/week</td>
</tr>
<tr>
<td>Average Demand Rate (( \lambda ))</td>
<td>1,153,846 chips/week</td>
<td>576,923 chips/week</td>
</tr>
<tr>
<td>Standard Deviation of Demand (( \sigma ))</td>
<td>576,923</td>
<td>1,730,769 chips</td>
</tr>
<tr>
<td>Max Allowable Inventory (( M ))</td>
<td>1,730,769 chips</td>
<td>1,730,769 chips</td>
</tr>
<tr>
<td>Average Inventory Level (( E[X] ))</td>
<td>451,246</td>
<td>865,385</td>
</tr>
<tr>
<td>Average Expedite Rate (( A ))</td>
<td>336,268</td>
<td>96,154</td>
</tr>
<tr>
<td>Average Curtailed Rate (( R ))</td>
<td>11,474</td>
<td>96,154</td>
</tr>
<tr>
<td>Cost of Contract Transportation (( c_c ))</td>
<td>2.33 $/kg</td>
<td>2.33 $/kg</td>
</tr>
<tr>
<td>Cost of Expedite Transportation (( c_e ))</td>
<td>9.66 $/kg</td>
<td>9.66 $/kg</td>
</tr>
<tr>
<td>Cost of Retaining Shipments (( c_d ))</td>
<td>0 $/kg</td>
<td>0 $/kg</td>
</tr>
<tr>
<td>Contract Lead Time (CLT)</td>
<td>4 days</td>
<td>Contract</td>
</tr>
<tr>
<td>Cost of Expedite Lead Time (eLT)</td>
<td>3 days</td>
<td>Expedite</td>
</tr>
<tr>
<td>Holding Cost (( h ))</td>
<td>35% annually</td>
<td>Delay</td>
</tr>
<tr>
<td>Average Selling Price (( ASP ))</td>
<td>35 $/chip</td>
<td>Contract Pipeline</td>
</tr>
<tr>
<td>Chips/kg</td>
<td>25 Chips/kg</td>
<td>Expedite Pipeline</td>
</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td><strong>$459,058</strong></td>
<td><strong>$439,597</strong></td>
</tr>
</tbody>
</table>
## Performance Tool - Report

### Sample savings – $0.07/chip

- **Improved margins**

### Logistics Cost Breakdown for ULPC Chips

![Bar chart showing cost breakdown](chart.png)

### Table: Units in Pipe and Value in Pipe

<table>
<thead>
<tr>
<th></th>
<th>Units in Pipe</th>
<th>Value in Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contract Chips per day</td>
<td>116,797</td>
<td>467,188</td>
</tr>
<tr>
<td>Expedite Chips per day</td>
<td>48,038</td>
<td>144,115</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>164,835</strong></td>
<td><strong>611,302</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Annual</th>
<th>% of Logistics Cost</th>
<th>% of Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline Inventory Cost</td>
<td>$7,488,455</td>
<td>32%</td>
<td>0.4%</td>
</tr>
<tr>
<td>On-hand Inventory Cost</td>
<td>$5,527,762</td>
<td>23%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Contract Transport</td>
<td>$3,962,313</td>
<td>17%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Expedite Transport</td>
<td>$6,756,555</td>
<td>28%</td>
<td>0.3%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>$23,735,086</td>
<td>100%</td>
<td>1.1%</td>
</tr>
</tbody>
</table>
Optimal Supply Rate – Single Echelon

- Intel’s control of contract supply rate $\mu$
- Fixed set of demand rate ($\lambda$), standard deviation ($\sigma$), maximum inventory ($M$), and $\mu^*$ that minimizes total cost

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Average Demand Rate ($\lambda$)</td>
<td>1,153,846 chips/week</td>
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<td>Max Allowable Inventory ($M$)</td>
<td>1,730,769 chips</td>
</tr>
<tr>
<td>Cost of Contract Transportation ($cc$)</td>
<td>$2.33/kg</td>
</tr>
<tr>
<td>Cost of Expedite Transportation ($ce$)</td>
<td>$9.66/kg</td>
</tr>
<tr>
<td>Cost of Retaining Shipments ($cd$)</td>
<td>$0/kg</td>
</tr>
<tr>
<td>Contract Lead Time ($cLT$)</td>
<td>4 days</td>
</tr>
<tr>
<td>Expedite Lead Time ($eLT$)</td>
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</tbody>
</table>

**OPTIMAL CONTRACT SUPPLY RATE ($\mu^*$):** 829,052 chips/week

**TOTAL COST:** $459,058

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Optimal Supply Rate – Sensitivity Analysis

- Single echelon model
- Effect on $\mu^*$
  - Demand and variance
  - Transportation costs and lead times
  - Holding costs and ASP

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Sensitivity Analysis – Total Cost

- Cost savings over current system
- Relationship with standard deviation ($\sigma$)
  - Pricing / negotiation with customers
Optimal Supply Rate – Multi-Echelon

- 1 RDC + up to 5 hubs
- Inputs - costs, lead times and demand for each lane
- Optimal contract supply rate for hubs and RDC

<table>
<thead>
<tr>
<th>Hub #4</th>
<th>Regional Distribution Center (RDC)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average Demand Rate (λ) 7,000 chips/week</td>
</tr>
<tr>
<td></td>
<td>Standard Deviation of Demand (σ) 2,000</td>
</tr>
<tr>
<td></td>
<td>Max Allowable Inventory (M) 10,000 chips</td>
</tr>
<tr>
<td></td>
<td>Cost of Contract Transportation (cc) $3.75/kg</td>
</tr>
<tr>
<td></td>
<td>Cost of Expedite Transportation (ce) $7.75/kg</td>
</tr>
<tr>
<td></td>
<td>Cost of Retaining Shipments (cd) $0/kg</td>
</tr>
<tr>
<td></td>
<td>Contract Lead Time (cLT) 7 days</td>
</tr>
<tr>
<td></td>
<td>Cost of Expedite Lead Time (eLT) 1 day</td>
</tr>
<tr>
<td></td>
<td>Holding Cost (h) 26% annually</td>
</tr>
<tr>
<td></td>
<td>Average Selling Price $35/chip</td>
</tr>
<tr>
<td></td>
<td>Chips/kg 25 chips/kg</td>
</tr>
<tr>
<td></td>
<td>Optimal Mu (μ*) 1,084 chips/week</td>
</tr>
</tbody>
</table>
Optimal Supply Rate – Sensitivity Analysis

- Multi-echelon model
- Effect on $\mu^*$ through entire network
  - Demand and variance
  - Transportation costs and lead times
  - Holding costs and ASP
Single vs. Multi-Echelon

- Intel moving to multi-echelon
- Performance under
  - Demand scenarios
  - Transportation options
- Premium for responsiveness
- Sensitivity analysis
  - Crossover point
Simulation Model

• Validate assumptions
  – Enriches theoretical model
    • Adds stochastic lead times
    • Finite product life-cycle
    • Does not assume constant supply rate
  – Verify real-world applicability

• Single and multi-echelon models

• Scenario analysis
  – Lifecycle testing
  – Specific lanes
Simulation Model - Results

- Model predictions vs. simulation results
- Predictive accuracy
Scenario Analysis

• Plan transportation strategy
  – Optimal contract supply rate

• Across product life cycle
  – Ramp up, peak, ramp down
  – Changes in demand, variance and holding rate

• Specific lanes
  – Penang → New Delhi
  – Costa Rica → Bangkok
  – Manila → Singapore
  – Shanghai → New Delhi
Scenario Analysis - Results

- Penang → New Delhi
- 2 year life cycle
  - 3 Phases - Demand behavior from historical data
- Simulation verification
  - Theoretical model assumes long run steady state
Additional Applications

• Transportation mode viability
  – Multiple transportation options in given geography
  – Infer viability from optimal supply rate

• Integration with high ASP supply chain
  – ULPC product through current high value network
  – Current high value product through ULPC network
Deliverables

• Tools
  – Single echelon performance model
  – Single echelon optimal contract supply rate tool
  – Multi-echelon optimal contract supply rate tool
  – Single vs. multi-echelon comparison tool

• Output interpretation manual
• Scenario analysis
• Report - key characteristics of low-cost supply chain
Potential Value

• Improve margins

• Flexible model
  – Within the model itself
  – Across various configurations

• Inform strategic decision making
  – Configuration of distribution network
  – Understanding of transportation requirements
  – Help negotiation with freight forwarders

• Trade-offs
  – Between inventory holding cost and transportation cost
  – Service levels and supply chain costs
Summary

- Focus - inventory holding vs. transportation costs
- Inventory model - controlled Wiener process
- Single echelon and multi-echelon models
- Performance model
- Optimal contract rate models
- Sensitivity analysis
- Validate through simulation
- Single echelon vs. multi-echelon comparison
- Potential value
Questions?