Intel Logistics

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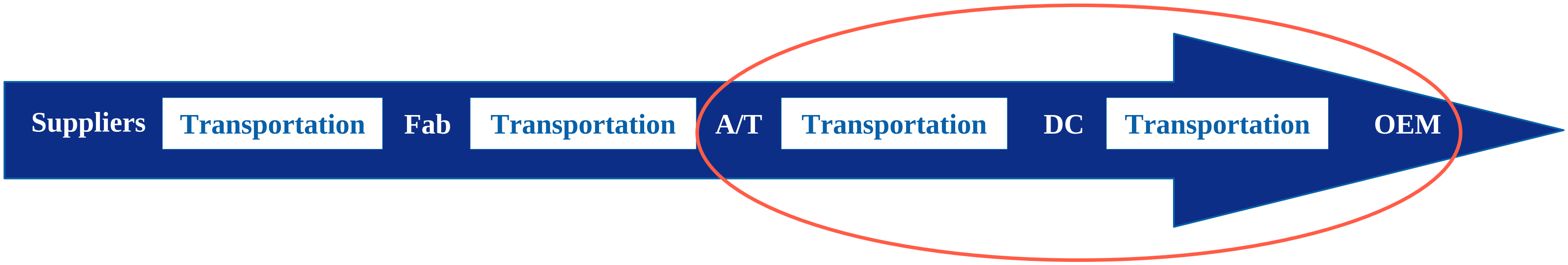
Agenda

- 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

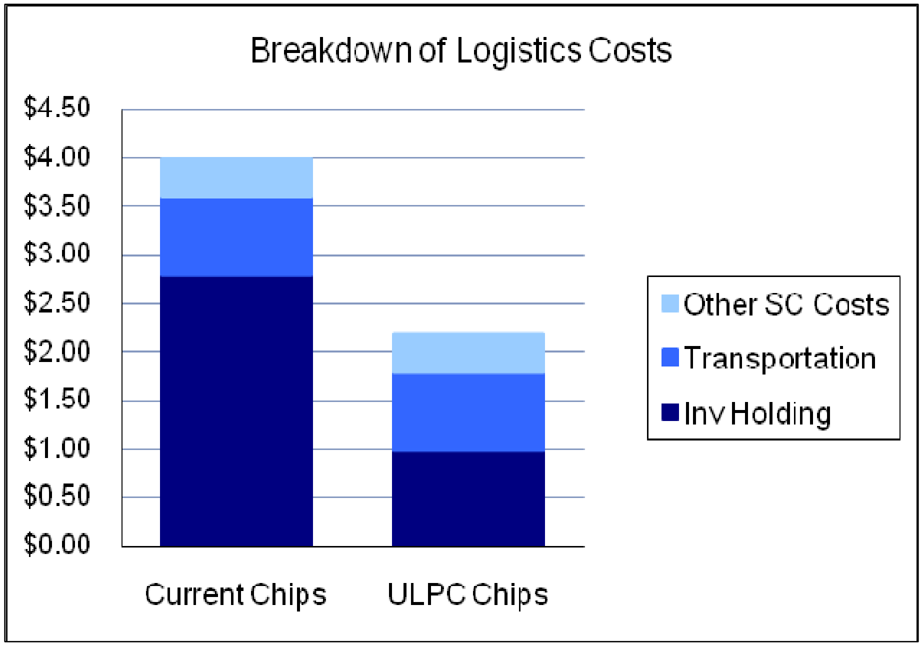


Problem Description

- 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.

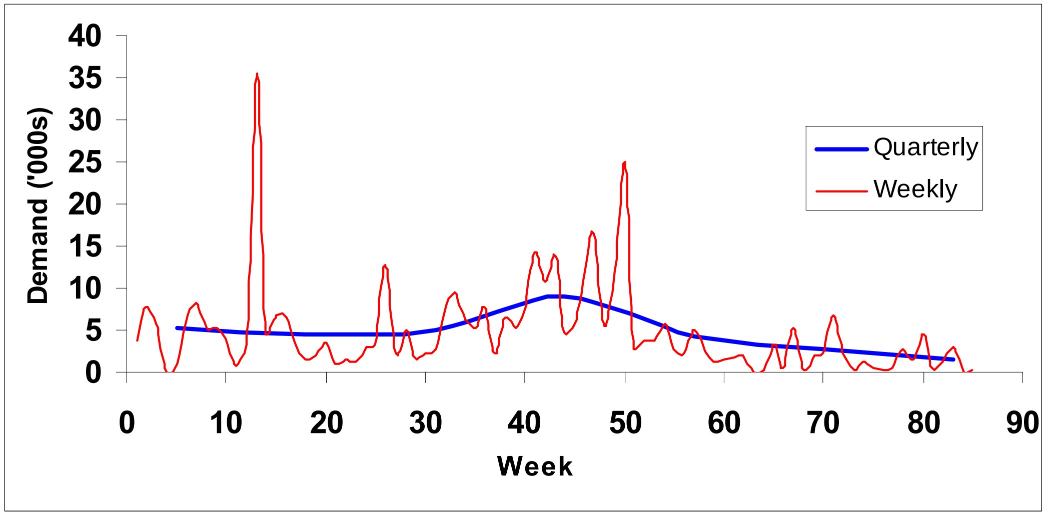
Objective

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

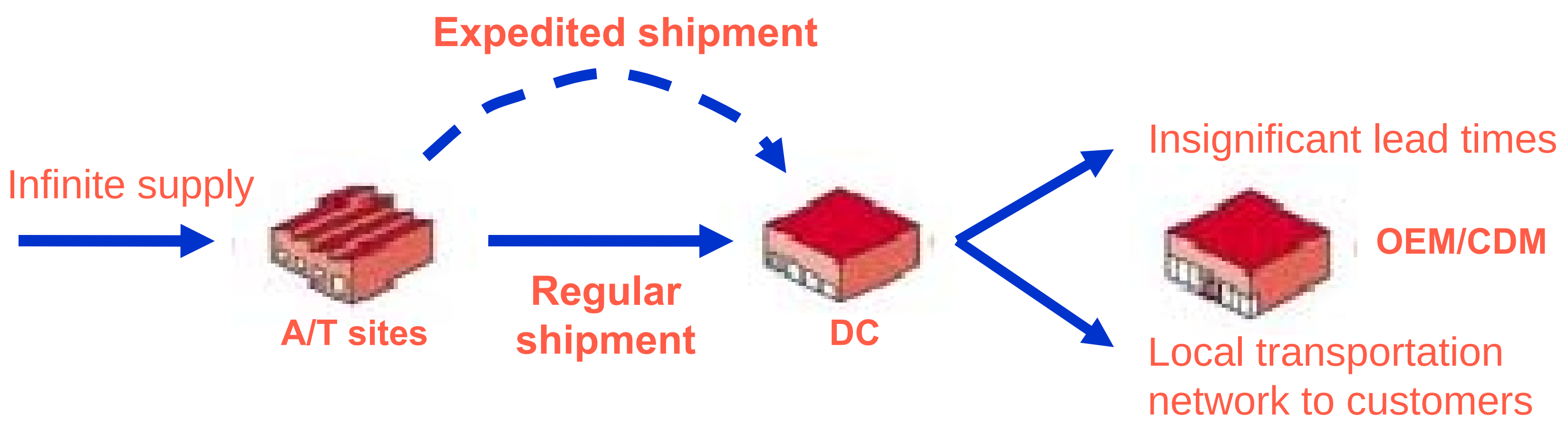
- Strategic vs. operational focus
- Regular and expedited transportation
- Single and multi-echelon system

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

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

μ(t) – Supply level

λ(t) – Demand level

σ – Standard deviation of netput

W(t) – Standard Wiener process

a(t) – Expedited shipments at time t

r(t) – Curtailed shipments at time t

$$A(T) = \int_0^T a(t)dt \qquad R(T) = \int_0^T r(t)dt$$

Inventory Model – Basic Adjoint Relationship

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

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

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

Gives us performance metrics

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

$\tilde{A}$ - Long run average expedite rate

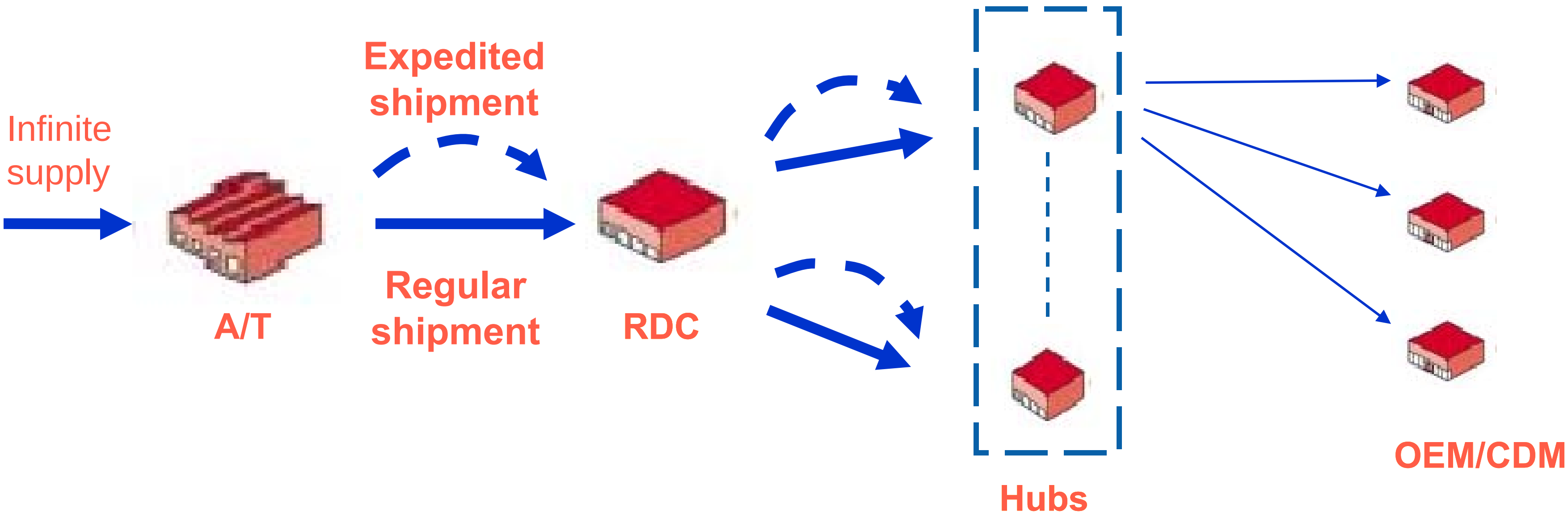
$\tilde{R}$ - Long run average curtailed rate

Inventory Model – Performance Metrics

Test functions: $f(X) = \left\{ X, \quad X^2, \quad e^{\frac{-2(\mu-\lambda)X}{\sigma^2}} \right\}$

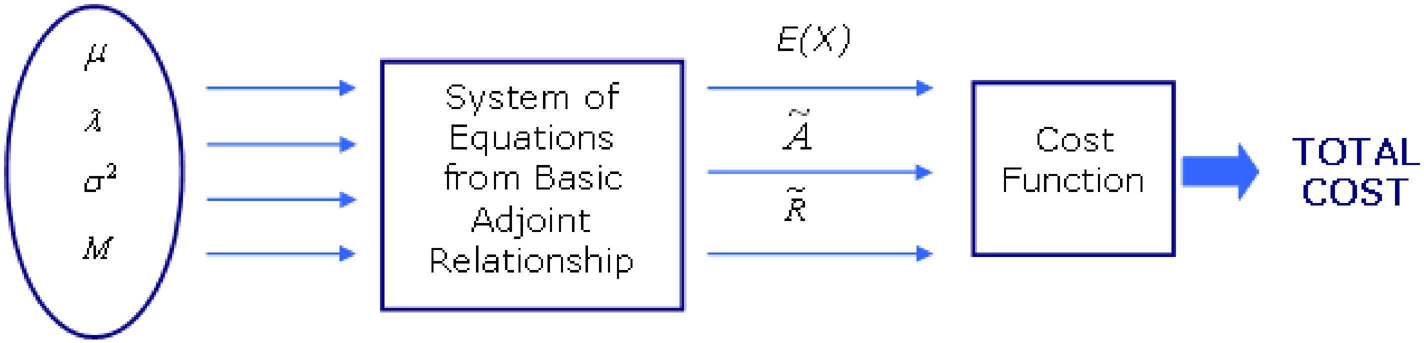
Performance Metric	μ ≠ λ	μ = λ
$E[X]$	$\frac{-\sigma^2 + e^{\frac{2M(\mu-\lambda)}{\sigma^2}}\left(2M(\mu-\lambda)+\sigma^2\right)}{\sigma^2}$	$\frac{M}{2}$
$\tilde{A}$	$\frac{\mu-\lambda}{e^{\frac{2M(\mu-\lambda)}{\sigma^2}}-1}$	$\frac{\sigma^2}{2M}$
$\tilde{R}$	$\frac{e^{\frac{2M(\mu-\lambda)}{\sigma^2}}(\mu-\lambda)}{e^{\frac{2M(\mu-\lambda)}{\sigma^2}}-1}$	$\frac{\sigma^2}{2M}$

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 = Cost of contract freight

C_e = Cost of expedited freight

C_d = Cost of delayed freight

P = Cost of pipeline inventory / time

h = 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

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

Where

$$\sum_{i=1}^{n} \sigma_i^{\,2} = \sigma^2 \qquad \sum_{i=1}^{n} \mu_i = \mu$$

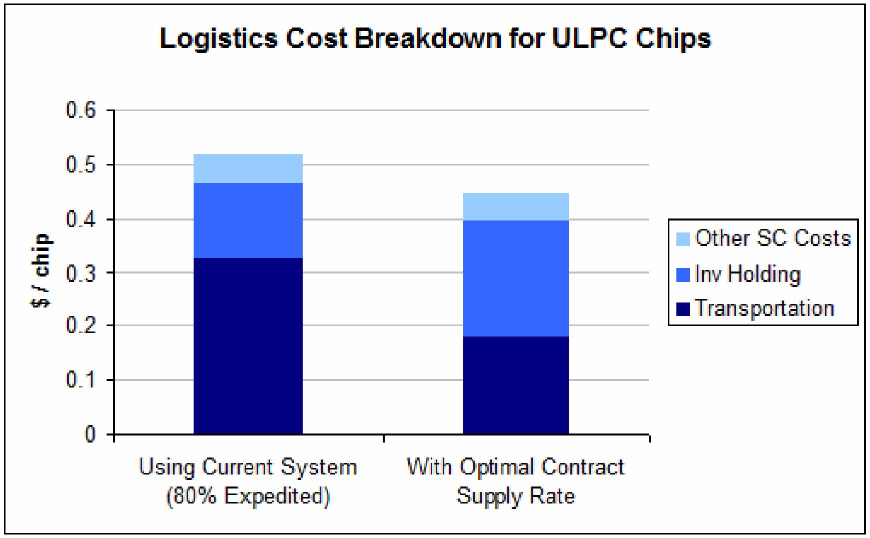
- BAR similar to single echelon $\Rightarrow$ same 3 test functions for performance metrics

Performance Model

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

Average Contract Supply Rate (μ)	829,052	chips/week		**General Case**	**When λ=μ**
Average Demand Rate (λ)	1,153,846	chips/week	Average Inventory Level (E[X])	451,246	865,385
Standard Deviation of Demand (σ)	576,923		Average Expedite Rate (A)	336,268	96,154
Max Allowable Inventory (M)	1,730,769	chips	Average Curtailed Rate (R)	11,474	96,154
Cost of Contract Transportation (cc)	2.33	$/kg			
Cost of Expedite Transportation (ce)	9.66	$/kg	**Costs**	**General Case**	**When λ=μ**
Cost of Retaining Shipments (cd)	0	$/kg	Holding	$106,303	$203,865
Contract Lead Time (cLT)	4	days	Contract	$77,268	$77,268
Cost of Expedite Lead Time (eLT)	3	days	Expedite	$129,934	$37,154
Holding Cost (h)	35%	annually	Delay	$0	$0
			Contract Pipeline	$111,603	$111,603
Average Selling Price (ASP)	35	$/chip	Expedite Pipeline	$33,950	$9,708
Chips/kg	25	Chips/kg	**TOTAL COST**	**$459,058**	**$439,597**

Performance Tool - Report



Sample savings – $0.07/chip

→ Improved margins

		Units in Pipe	Value in Pipe
Contract Chips per day	116,797	467,188	$ 16,351,573
Expedite Chips per day	48,038	144,115	$ 5,044,012
Total	164,835	611,302	$ 21,395,586
	Annual	% of Logistics Cost	% of Revenue
Pipeline Inventory Cost	$ 7,488,455	32%	0.4%
On-hand Inventory Cost	$ 5,527,762	23%	0.3%
Contract Transport	$ 3,962,313	17%	0.2%
Expedite Transport	$ 6,756,555	28%	0.3%
Total	$ 23,735,086	100%	1.1%

Optimal Supply Rate – Single Echelon

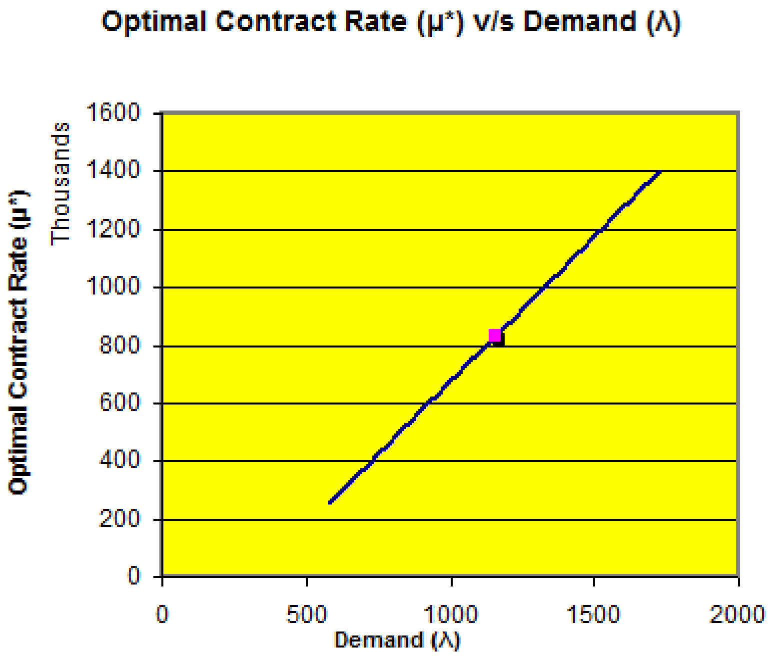
- Intel's control of contract supply rate μ
- Fixed set of demand rate (λ), standard deviation (σ), maximum inventory (M), and μ* that minimizes total cost

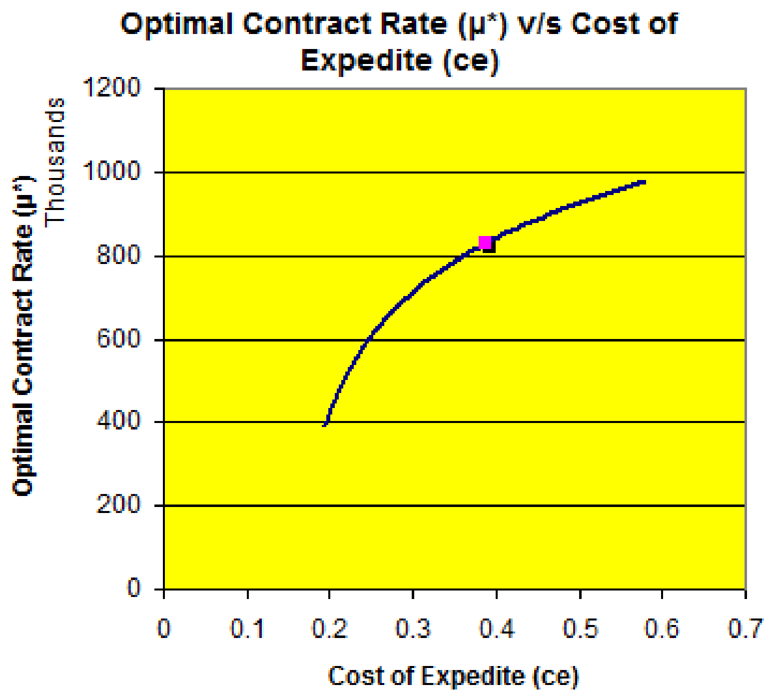
Average Demand Rate (λ)	1,153,846	chips/week
Standard Deviation of Demand (σ)	576,923	
Max Allowable Inventory (M)	1,730,769	chips
Cost of Contract Transportation (cc)	2.33	$/kg
Cost of Expedite Transportation (ce)	9.66	$/kg
Cost of Retaining Shipments (cd)	0	$/kg
Contract Lead Time (cLT)	4	days
Expedite Lead Time (eLT)	3	days
Holding Cost (h)	35%	annually
Average Selling Price (ASP)	35	$/chip
Chips/kg	25	Chips/kg
OPTIMAL CONTRACT SUPPLY RATE (μ*)	**829,052**	**chips/week**
TOTAL COST	**$459,058**	

Solve for μ* ONLY

Solve for μ* + Sensitivity

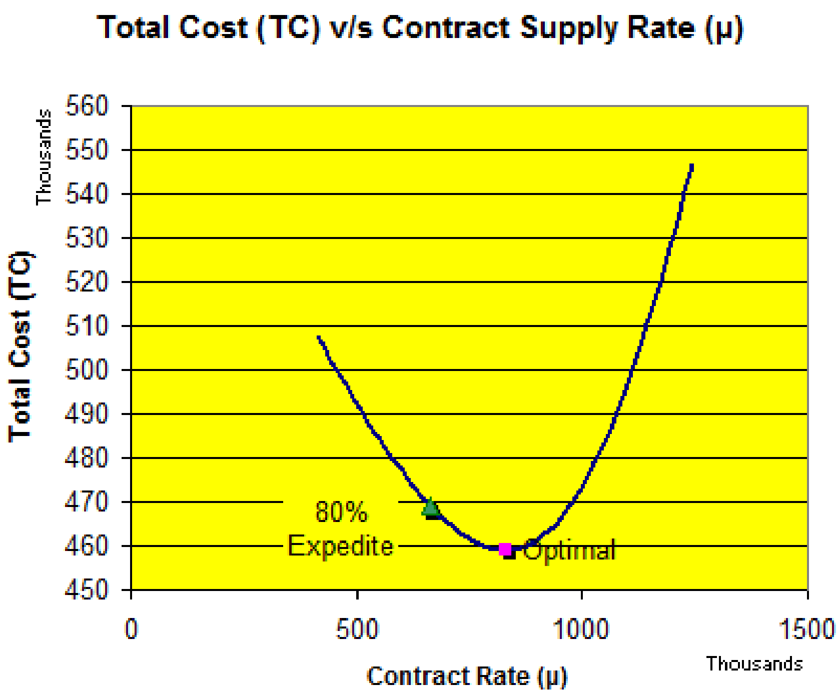
Optimal Supply Rate – Sensitivity Analysis

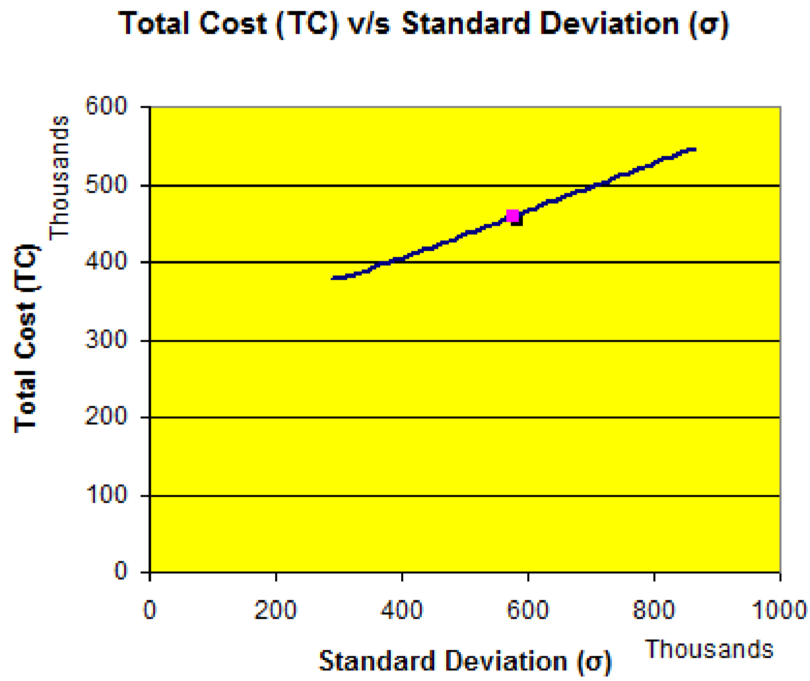




- Single echelon model
- Effect on μ*
  - Demand and variance
  - Transportation costs and lead times
  - Holding costs and ASP

Sensitivity Analysis – Total Cost





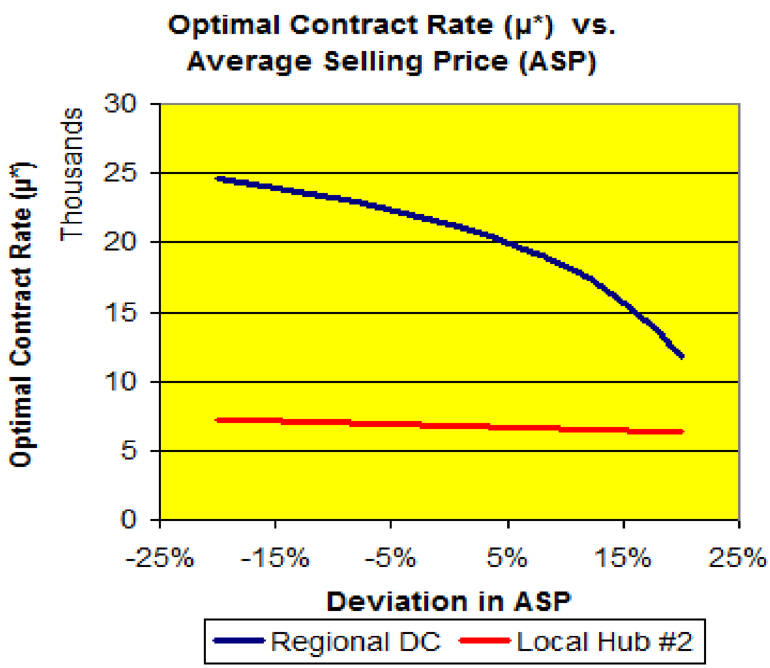
- Cost savings over current system
- Relationship with standard deviation (σ)
  - Pricing / negotiation with customers

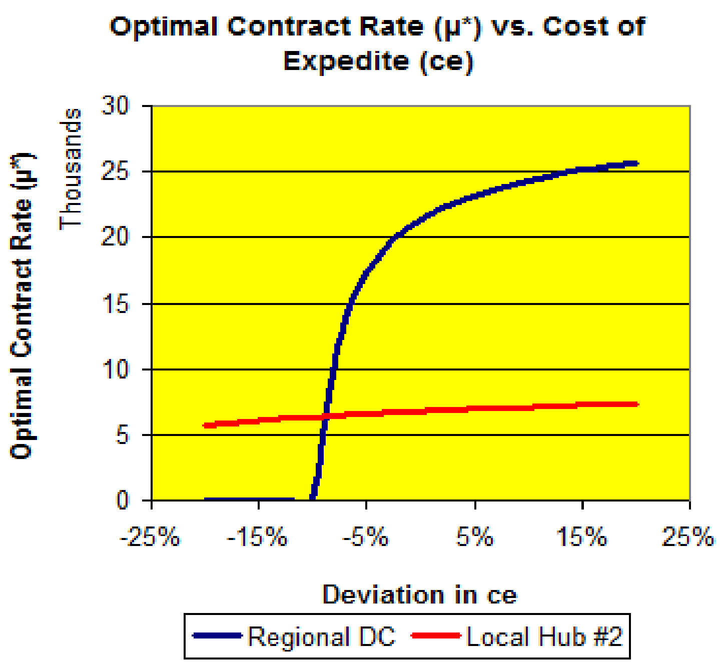
Optimal Supply Rate – Multi-Echelon

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

Hub # 4			Regional Distribution Center (RDC)		
Average Demand Rate (λ)	7,000	chips/week	Average Demand Rate (λ)	32,000	chips/week
Standard Deviation of Demand (σ)	2,000		Standard Deviation of Demand (σ)	6,265	
Max Allowable Inventory (M)	10,000	chips	Max Allowable Inventory (M)	70,000	chips
Cost of Contract Transportation (cc)	3.75	$/kg	Cost of Contract Transportation (cc)	3.75	$/kg
Cost of Expedite Transportation (ce)	7.75	$/kg	Cost of Expedite Transportation (ce)	7	$/kg
Cost of Retaining Shipments (cd)	0	$/kg	Cost of Retaining Shipments (cd)	0	$/kg
Contract Lead Time (cLT)	7	days	Contract Lead Time (cLT)	6	days
Cost of Expedite Lead Time (eLT)	1	days	Cost of Expedite Lead Time (eLT)	2	days
Holding Cost (h)	26%	annually	Holding Cost (h)	26%	annually
Average Selling Price	35	$/chip	Average Selling Price	35	$/chip
Chips/kg	25	chips/kg	Chips/kg	25	chips/kg
Optimal Mu (µ*)	**1,084**	**chips/week**	**Optimal Mu (µ*)**	**21,300**	**chips/week**

Optimal Supply Rate – Sensitivity Analysis

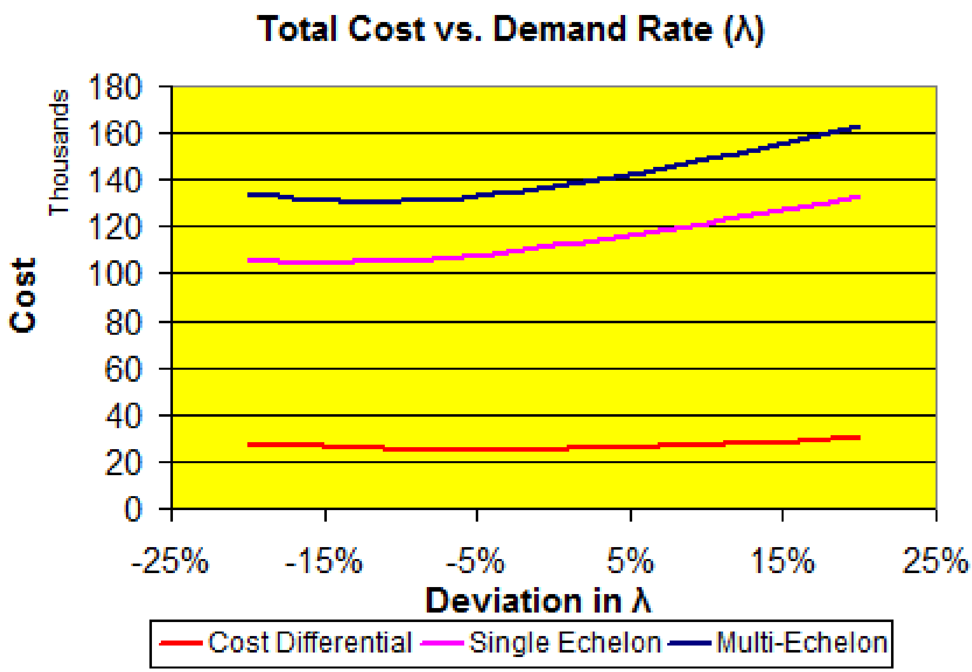




- Multi-echelon model
- Effect on μ* through entire network
  - Demand and variance
  - Transportation costs and lead times
  - Holding costs and ASP

Single vs. Multi-Echelon

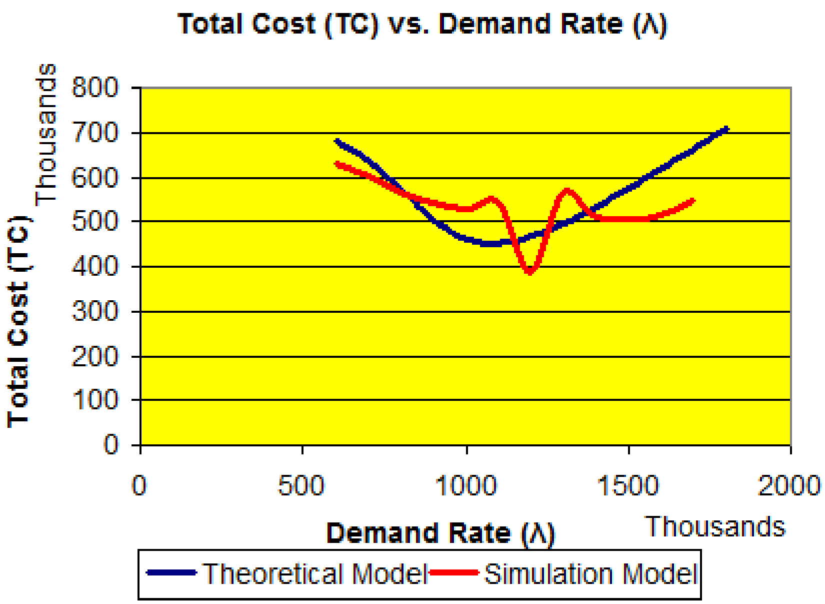
- Intel moving to multi-echelon
- Performance under
  - Demand scenarios
  - Transportation options
- Premium for responsiveness
- Sensitivity analysis
  - Crossover point

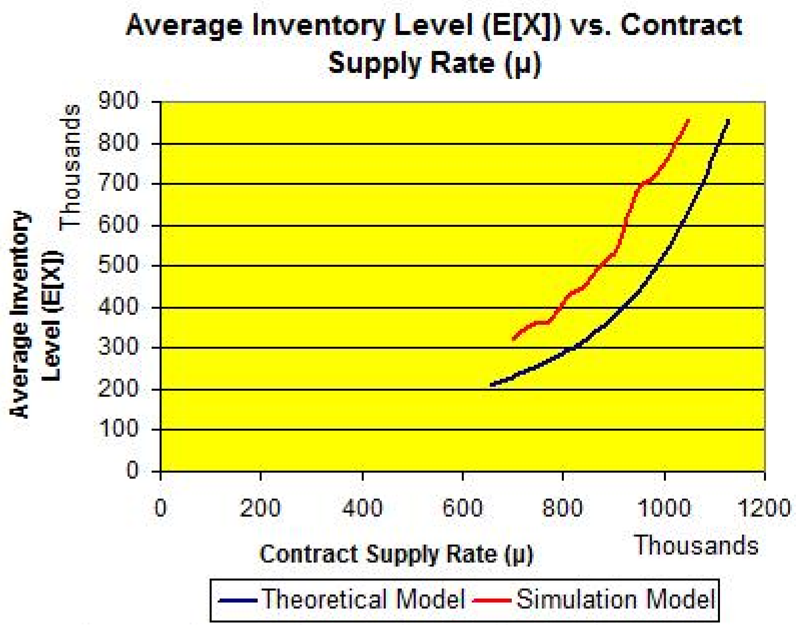


Simulation Model

- 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



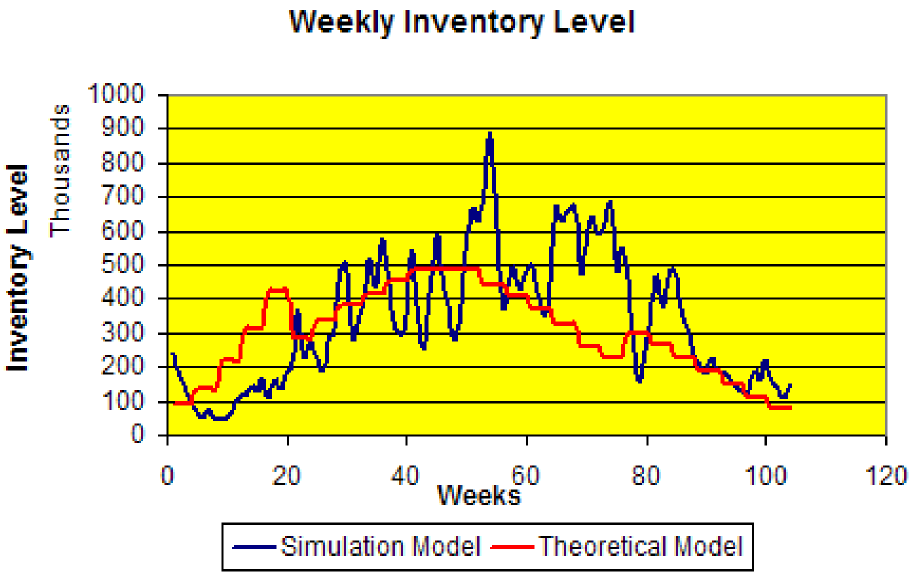


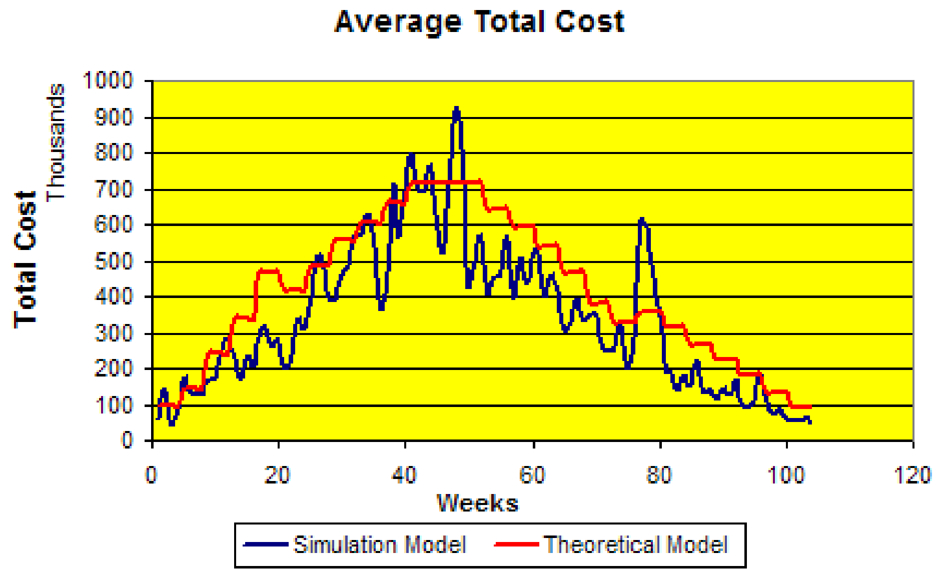
- Model predictions vs. simulation results
- Predictive accuracy

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?