Managing Inventory in Global Supply Chains Facing Port-of-Entry Disruption Risks

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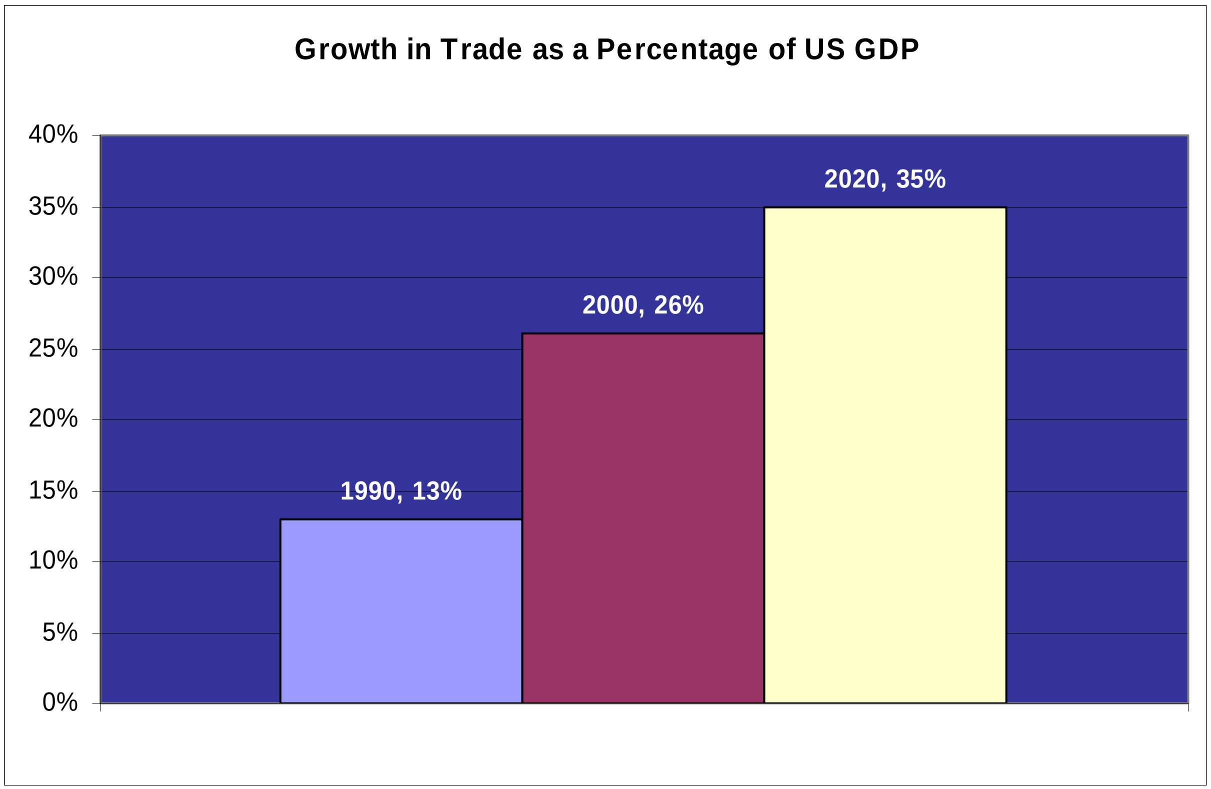
13 October 2008

Initial comments

- Prevention, identification, response, recovery from major disruptions
- Security
- Ancillary benefits
  - More generally, major disruptions
  - Productivity (economic strength, private sector perspective)
  - Pilferage
- Use of information technology – real-time supply chain control, based on real-time data for the next level of productivity, resilience (downside risk mitigation), and stability

Importance of trade for economic strength

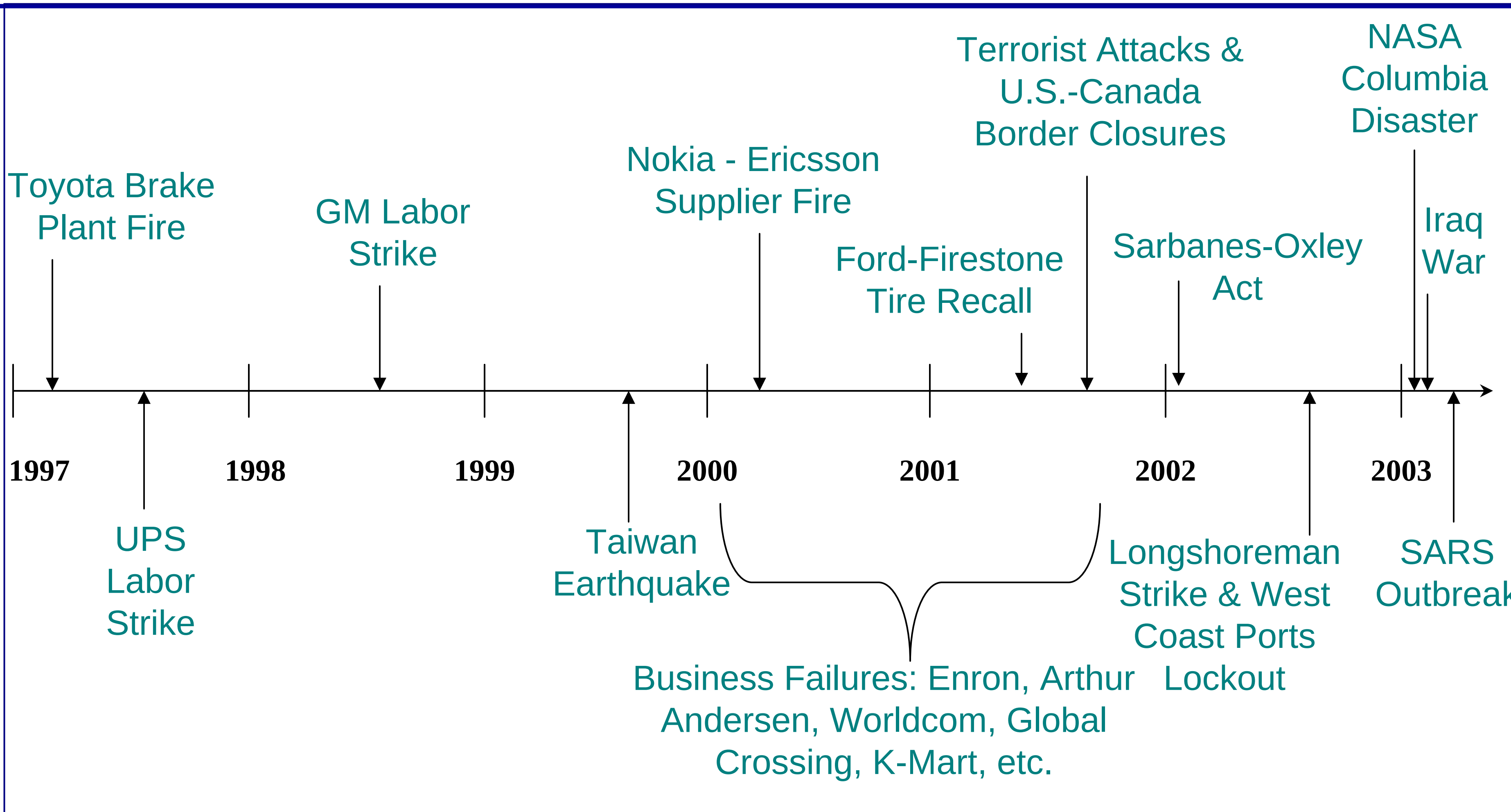


Supply chain resiliency

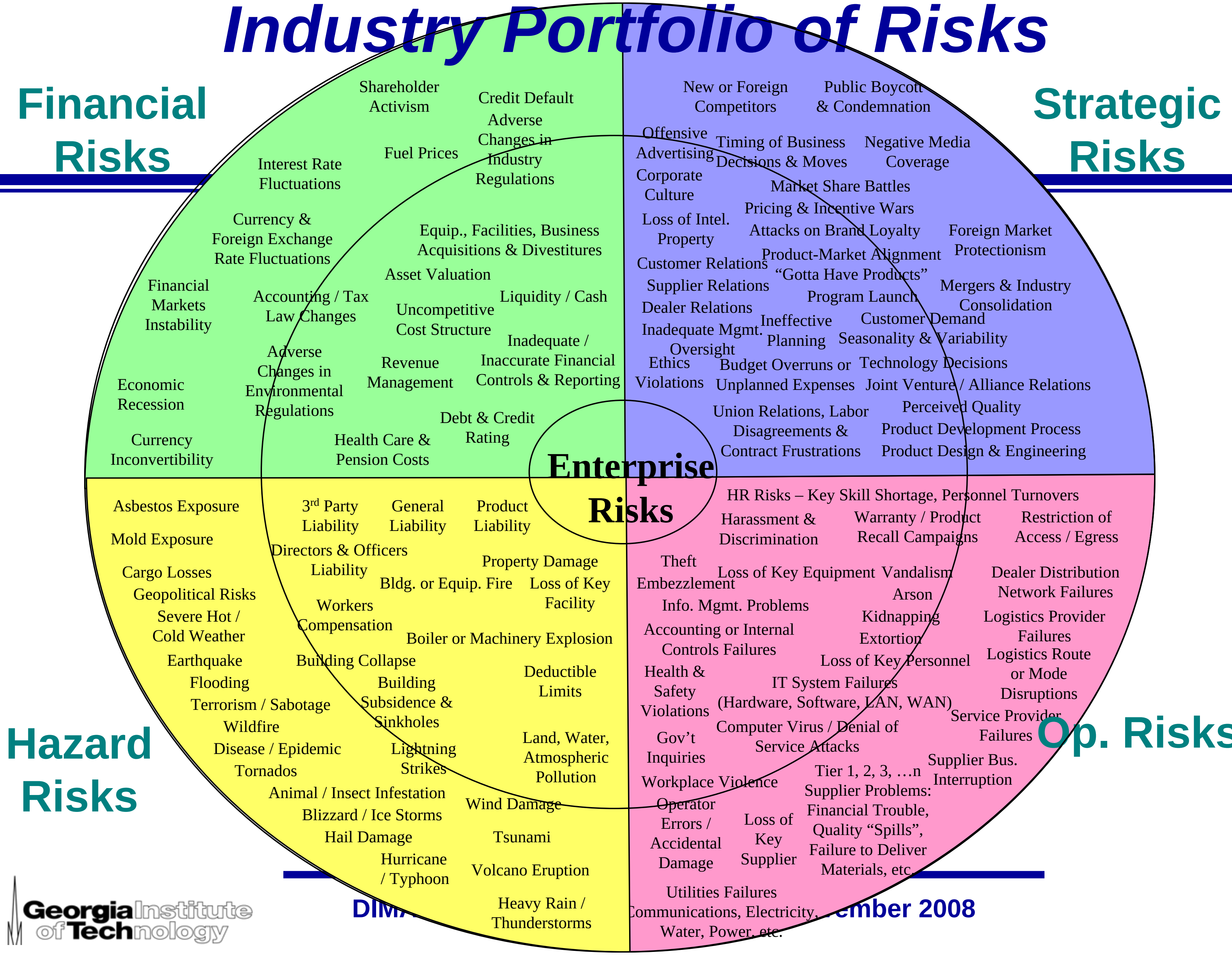
Uncertainty & major disruption

- Uncertainty – dealing explicitly with stochastic effects, e.g., variability in demand, supply, congestion, driver availability
- Major disruption – a loss of nodes &/or links in the global freight transportation network
- Resiliency in supply chains – preventing, gracefully reacting to, and quickly recovering from major disruptions
- Comment: lean supply chains are notoriously fragile
- Policy implication – the balance in investment between prevention & quick recovery
- R&D challenge – for models of sequential decision making (e.g., route finding, MDP), a weighted sum of a multiplicative criterion and an additive criterion produces violations of the Principle of Optimality (dynamic programming); games

Supply Chain Disruptions



Industry Portfolio of Risks



Inventory Control with Risk of Major Supply Chain Disruptions

Brian M. Lewis, Alan Erera, Chelsea C. White III

Outline

- Motivation and Introduction
- Part 1: An Inventory Control Model with Border Closures
- Part 2: An Inventory Control Model with Border Closures and Congestion

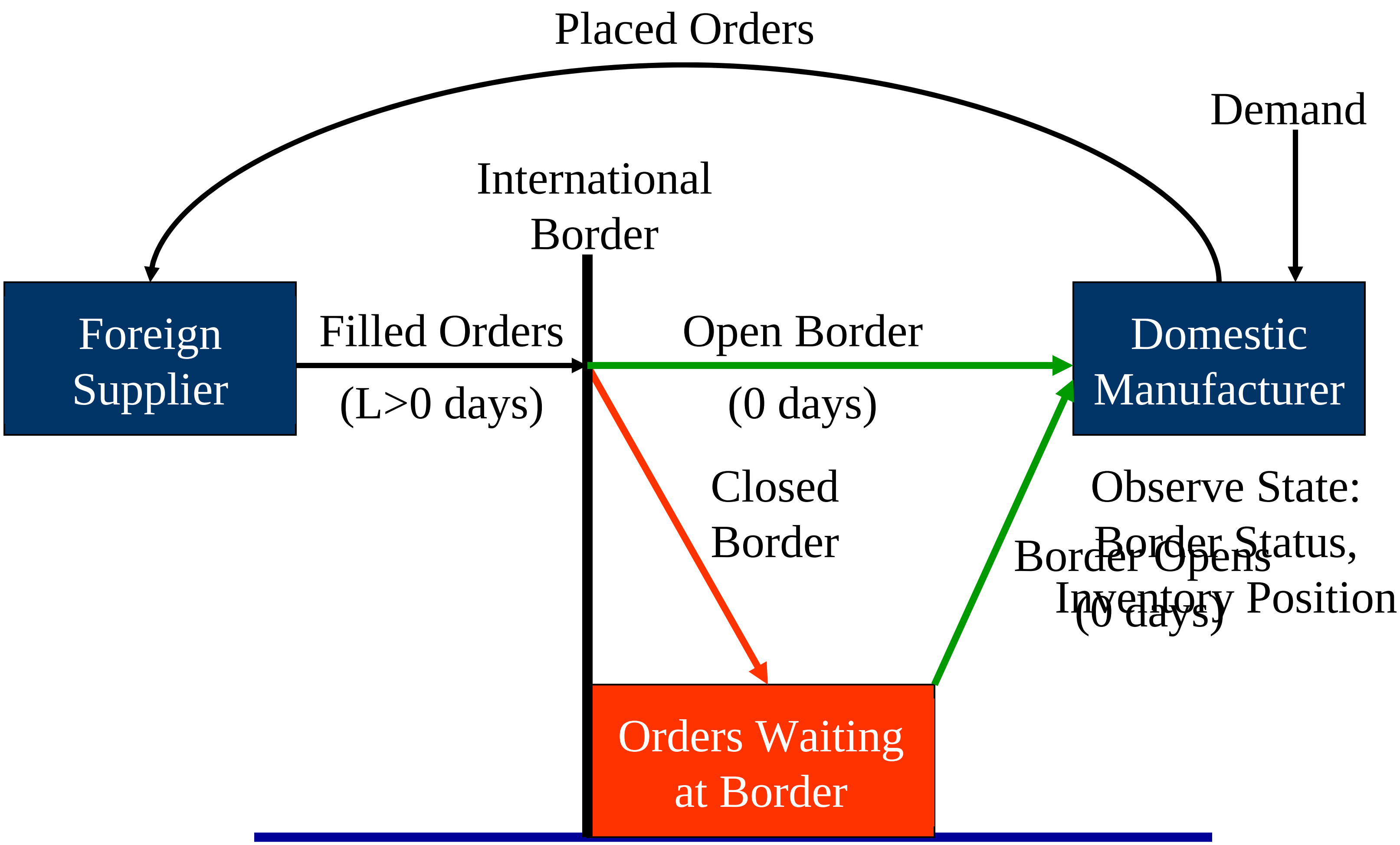
Motivation and introduction

- Supply chain security has evolved: from cargo theft to WMD and border closures
- Increased focus on supply chain security post-9/11: C-TPAT, CSI, 24-hour rule
- Research motivated by possibility of port of entry closures
  - September 11 terrorist attacks
    - US-Canadian border delays: minutes to 12 hours
    - US air traffic grounded
  - 2003 BAH Port Security Wargame
    - Simulated terrorist attack with “dirty bomb” in containers
    - All US ports closed for 8 days, Backlog takes 92 days to clear
  - 2002 10-day labor lockout at 29 Western US seaports
    - Congestion and delays lasted for months

Motivation and introduction

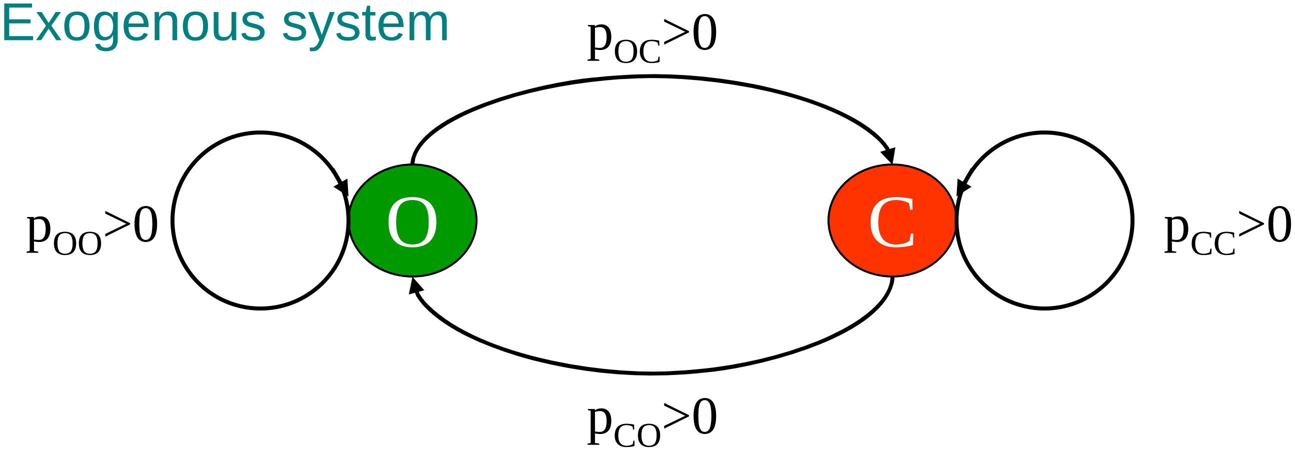
- Questions:
  - How can we model major supply chain disruptions (e.g. border closures and congestion) within an inventory control framework?
  - What does an optimal inventory policy look like?
  - How are an optimal policy and the long-run average cost affected by the system parameters?
  - What managerial and policy insights does the model provide?

Part 1: An Inventory Control Model with Border Closures



Problem statement

- Border system
  - Modeled by a DTMC
  - State space, S ={"O"= Open, "C"= Closed}
  - Exogenous system



Problem statement

- Outstanding order vector, $\mathbf{z}=\{z_{kt}\}$
  - $k \in \{0,1,2,\ldots, L-1\}$: orders that have been outstanding for **exactly** k days
  - L: orders that have been outstanding for **at least** L days
  - g: orders that have arrived
- Order movement function

$$M(k|O) = \begin{cases} k+1 & \text{if } 0 \leq k < L, \\ \gamma & \text{if } k = L. \end{cases}$$

$$M(k|C) = \begin{cases} k+1 & \text{if } 0 \leq k < L, \\ L & \text{if } k = L. \end{cases}$$

  - Order crossover is prevented

Problem statement

- Long-run average cost criterion - no discounting future costs
- Costs – purchase, holding, penalty
- Demand - bounded, non-negative, integer-valued, iid
- Specialize Song and Zipkin (1996) model
  - Stationary state-dependent, basestock policies optimal (denoted, **y**)
    - Reduced sufficient state information: (i_t, x_t)
  - Ordering decision rule at time *t* is

$$\delta(i_t, x_t) = \begin{cases} y(i_t) - x_t & \text{if } x_t < y(i_t), \\ 0 & \text{if } x_t \geq y(i_t). \end{cases}$$

Theoretical results

- *For the border closure model without congestion,* $y^*(O) = y^*(C) = \widehat{y}^*$.
- *The optimal state-invariant order-up-to level ($\widehat{y}^*$) is non-decreasing in the cost ratio* $\left(\frac{p}{p+h}\right)$.
- *The optimal state-invariant order-up-to level ($\widehat{y}^*$) is non-decreasing in the penalty cost (p) and non-increasing in holding cost (h).*
- *The optimal state-invariant order-up-to level ($\widehat{y}^*$) is non-decreasing in the minimum leadtime (L).*

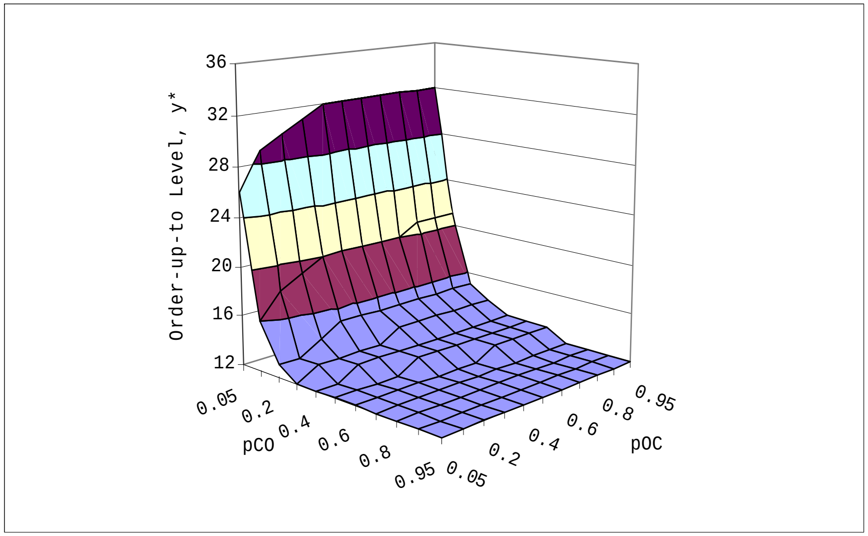
Numerical Study

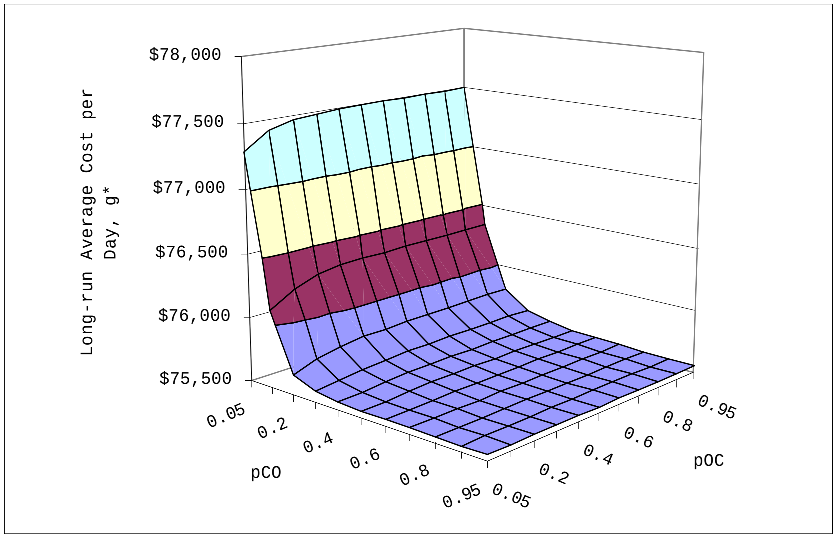
- Daily review

Parameter	Values
Purchase Cost, c	$150,000
Holding Cost, h	$100, $500
Penalty Cost, p	$1,000, $2,000
Minimum Leadtime, L	1, 7, 15
Transition Probability, p_{OC}	0.001, 0.003, 0.01, 0.02, 0.05, 0.1, 0.2,...,0.8, 0.9, 0.95
Transition Probability, p_{CO}	0.05, 0.1, 0.2,...,0.8, 0.9, 0.95
Demand Distribution	Poisson(Mean=0.5), Poisson(Mean=1)

Impact of the transition probabilities:

L=*15*, h=*$100*, p=*$1,000*, D~*Poisson(0.5)*

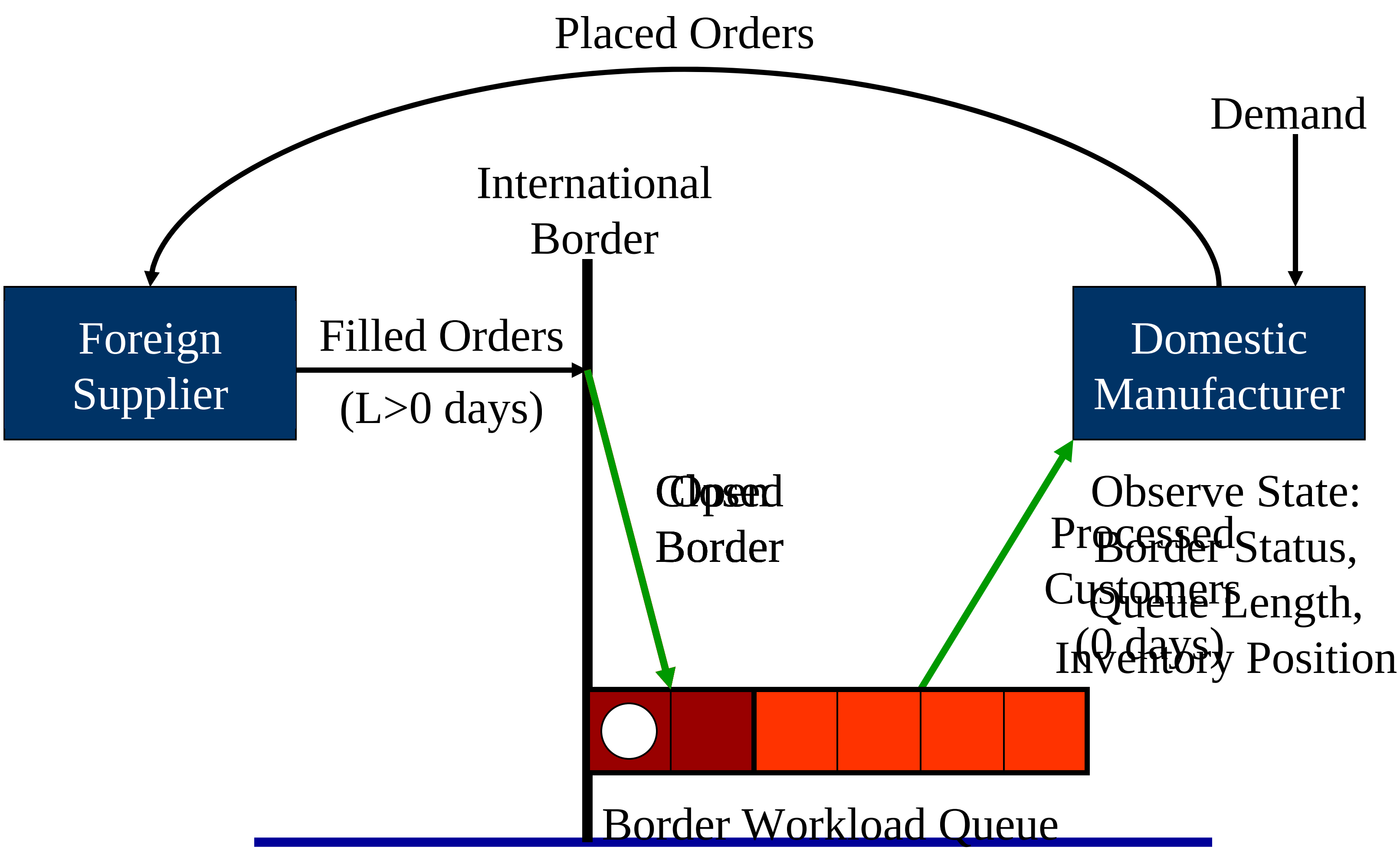




Impact of the transition probabilities

- Observations:
  - *Order-up-to level and long-run average cost are non-decreasing in p_{OC} and non-increasing in p_{CO}.*
  - *The expected duration of a closure ($1/p_{CO}$) more negatively affects a firm's productivity than the probability of a closure (p_{OC}).*
  - *Implications for the cooperation between business and government in disruption management and contingency planning.*

Part 2: An Inventory Control Model with Border Closures and Congestion



Results

- *For the border closure model with congestion, the optimal order-up-to levels (y*(i,n)) are dependent on border state (i) and border workload queue length (n).*
- *Order-up-to level and long-run average cost are non-decreasing in p_{OC} and non-increasing in p_{CO}.*
- *The expected duration of a border closure ($1/p_{CO}$) more negatively affects a firm's productivity than the probability of a border closure (p_{OC}).*
- *Order-up-to level and long-run average cost are more sensitive to the transition probabilities than in the model without congestion.*

Perishable Product Transportation with Costly Observation

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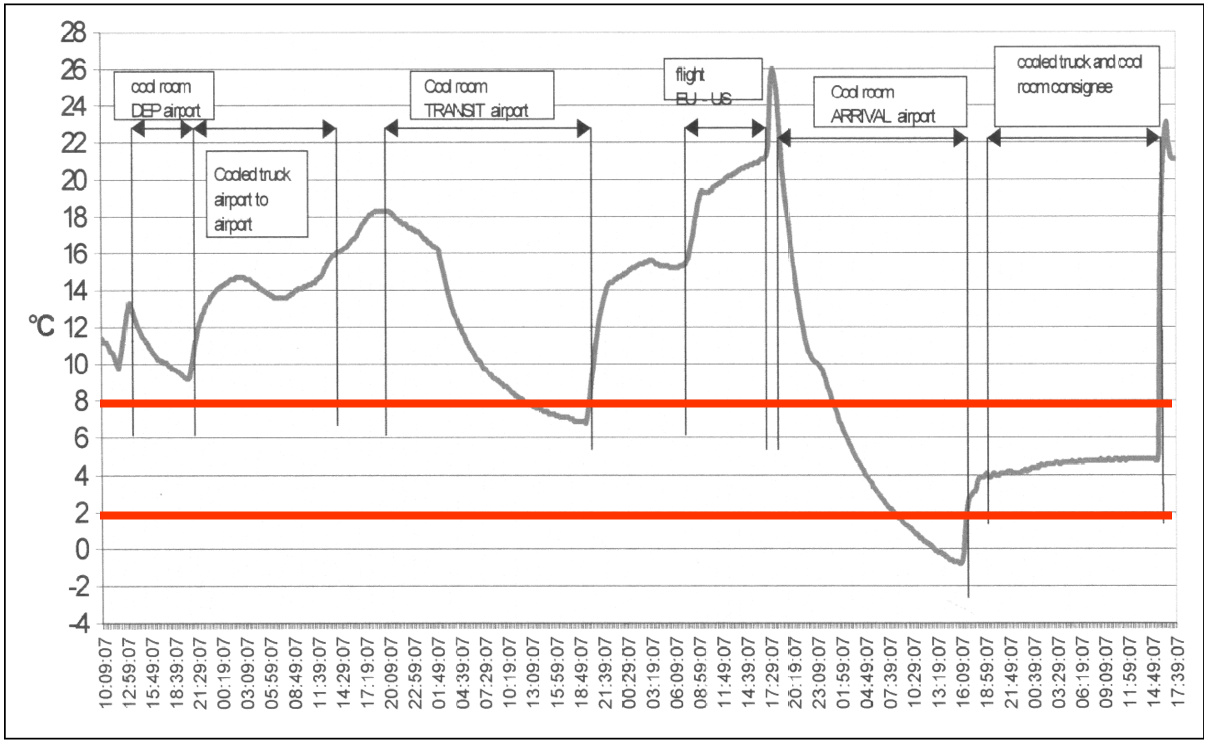
Problem

- How to most effectively transport perishable freight from origin to destination
- Common practice: try to control temperature in transit. If goods perish, then discard at the destination.
- Question: how valuable would it be to check freight at intermediate locations between origin and destination and abort transport once it is determined freight is spoiled?
- Example: Transport temperature sensitive freight from Japan to LA/LB to Atlanta.

Temperature control in reality



Temperatures in an air freight shipment with the instruction to maintain temperatures between 2 ℃ and 8 ℃ (Heap, 2006)

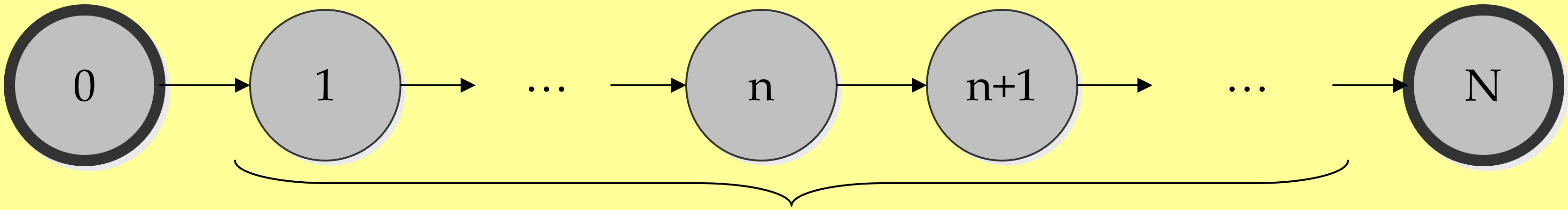
Economic impact of food spoilage

- 19% of food consumed in U.S. is grown in other countries
- Up to 20% of food is discarded due to spoilage (FDA)
- U.S. food industry annually discards $35 billion worth of spoiled goods (Forbes Magazine, April 24, 2006)
- 25% of all vaccine products reach their destination in a degraded state (Black, 2003, quoting WHO)

Black, A., E-Logistics in Cold Chain Management, http://www.samedanltd.com/members/archives/EPC/Summer2003/AlastairBlack.htm

Problem Statement

Problem Setting



Origin

W: wholesale purchase cost

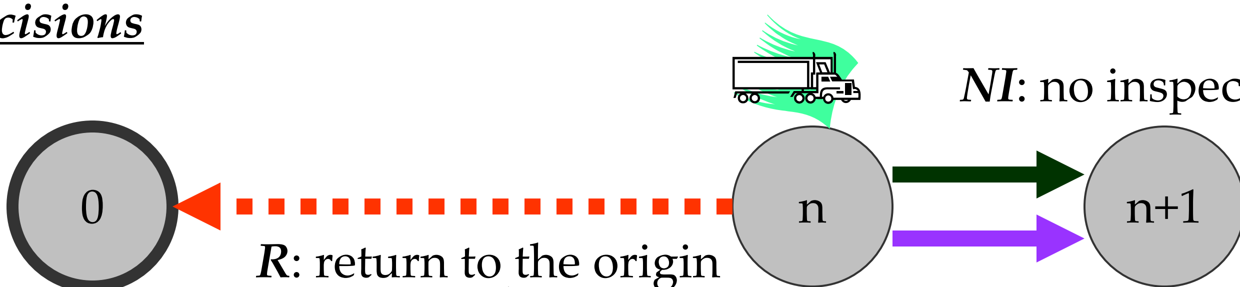
Intermediate Inspection Points

c(n,n+1): transportation cost from n to (n+1)

Destination

Rs: reward for state s

Decisions



NI: no inspection at (n+1)

R: return to the origin

I: perform inspection at (n+1)

Ds: disposal cost for state s

M: inspection cost

$$C(n) = c(n, n-1) + \beta c(n-1, n-2) + \cdots + \beta^{n-1} c(0,1)$$

States

- (S+1) states: *0* (fresh), *1*, …, *S* (spoiled)
- *P*: State transition probability matrix from location *n* to (*n+1*)

Conclusion

- Value of information - Investigated the value of having the choice to inspect freight quality at intermediate locations in transit
- Business implications:
  - Better inform decision to invest in IT infrastructure
  - Better understanding of how to set price; what profit to expect
  - Operationally, when to optimally inspect
- Basic knowledge creation:
  - Structure of optimal reward functions & optimal policies
  - Bound on value of information
  - Real time algorithmic development
- Future research: use of inspection information for:
  - Expedite decisions in inventory systems
  - Security

Thank you

Extra slides

Real-time supply chain control, based on real-time data

Where do the data come from?

- Inventory levels
- Production rates
- Vehicle, vessel, or trailer
  - Position
  - Speed
  - Direction
  - Temperature
  - Oil or air pressure
- Driver alertness
- Traffic congestion
- Weather
- Freight status & visibility

Real time control, based on real time data

- The next level of supply chain efficiency, resilience, stability
- What's the value of real-time data? Is it worth the IT infrastructure investment?
- Operationally, how to extract the value (optimally, sub-optimally) of real-time data?
- Dealing with data corruption: sensors, transmission, processing
- What is impact of data processing delay on information value?
- Are we sure that improved system observation will improve system performance?