Variability

- The Bull Whip Effect
- A Vicious Cycle
- Build-to-Order, Lean, JIT, …
- Managing Variability: A different view of inventory

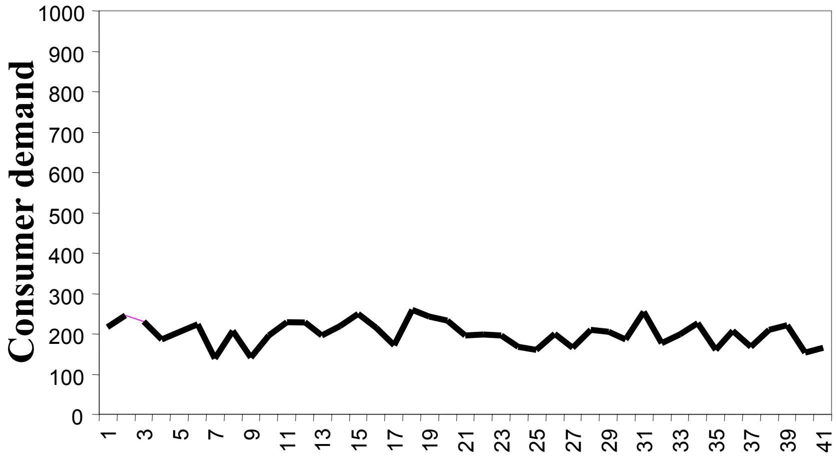
Example

Procter & Gamble: Pampers

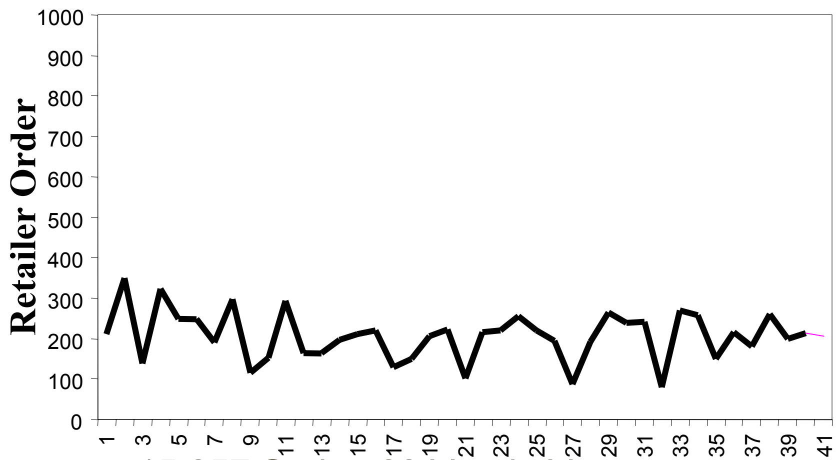
- Smooth consumer demand
- Fluctuating sales at retail stores
- Highly variable demand on distributors
- Wild swings in demand on manufacturing
- Greatest swings in demand on suppliers

Illustration

Consumer Sales at Retailer

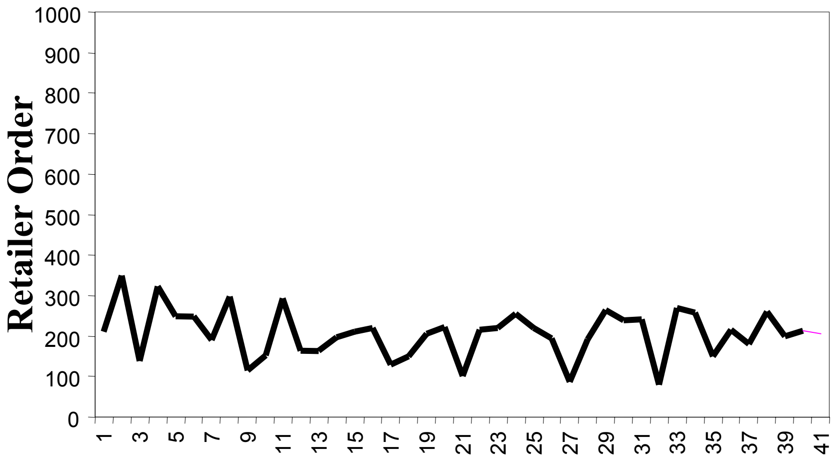


Retailer's Orders to Distributor

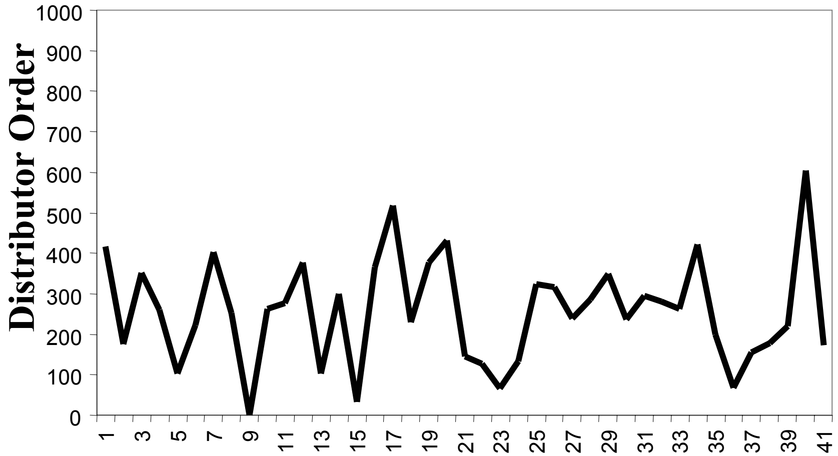


Illustration

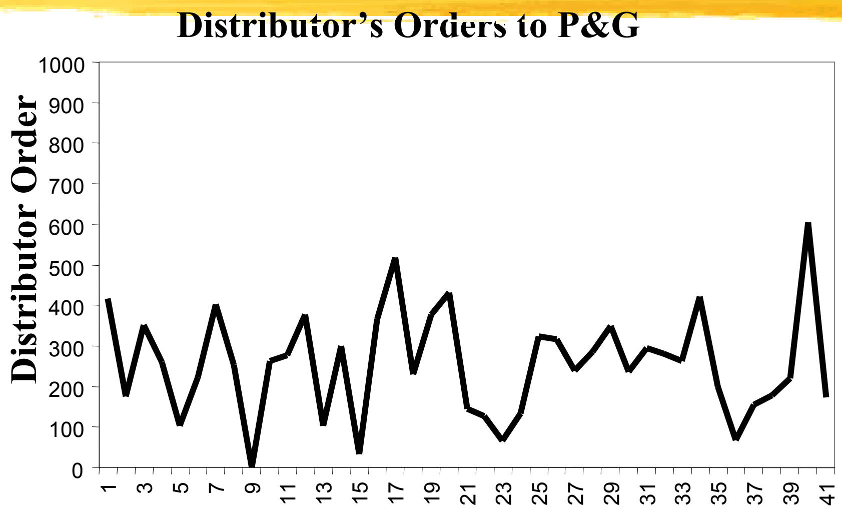
Retailer's Orders to Distributor

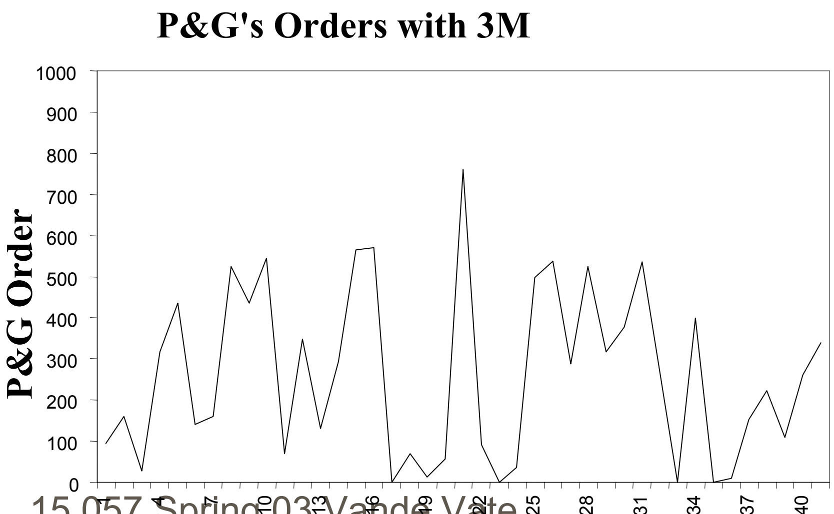


Distributor's Orders to P&G



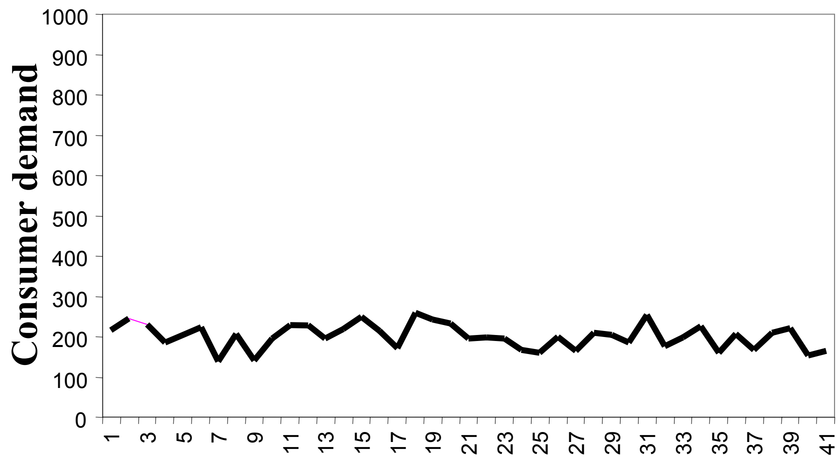
Illustration



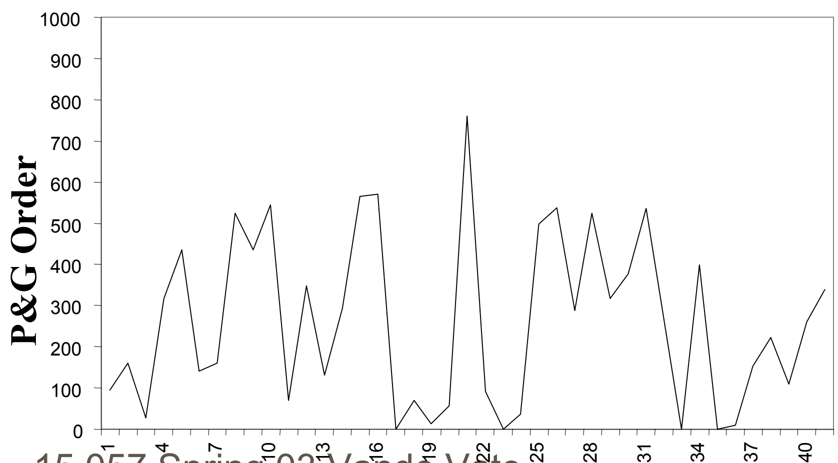


Illustration

Consumer Sales at Retailer



P&G's Orders with 3M



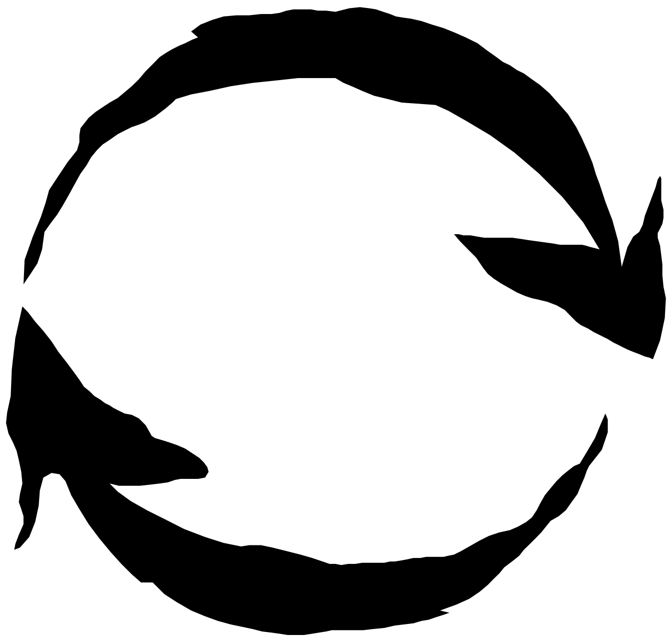
What Are the Effects?

What problems, costs, challenges does this create for the players in the supply chain?

What problems does this create for the product in the market place?

Forecasting

More variability



Poorer forecasts

Less reliable supply

Causes of Bullwhip Today

- Product Proliferation/Mass Customization
  - More varieties of products
- Build-to-Order
  - Prohibits pooling orders to smooth requirements
- Lean
  - Prevents pooling releases to smooth demand on the supply chain

Why Lean (Just-In-Time)?

- Reduces inventory
  - Capital requirements
  - Etc
- Reduces handling
  - Direct-to-Line
- Improves Quality
  - See problems quickly
- Increases launch speed

Why Not Lean?

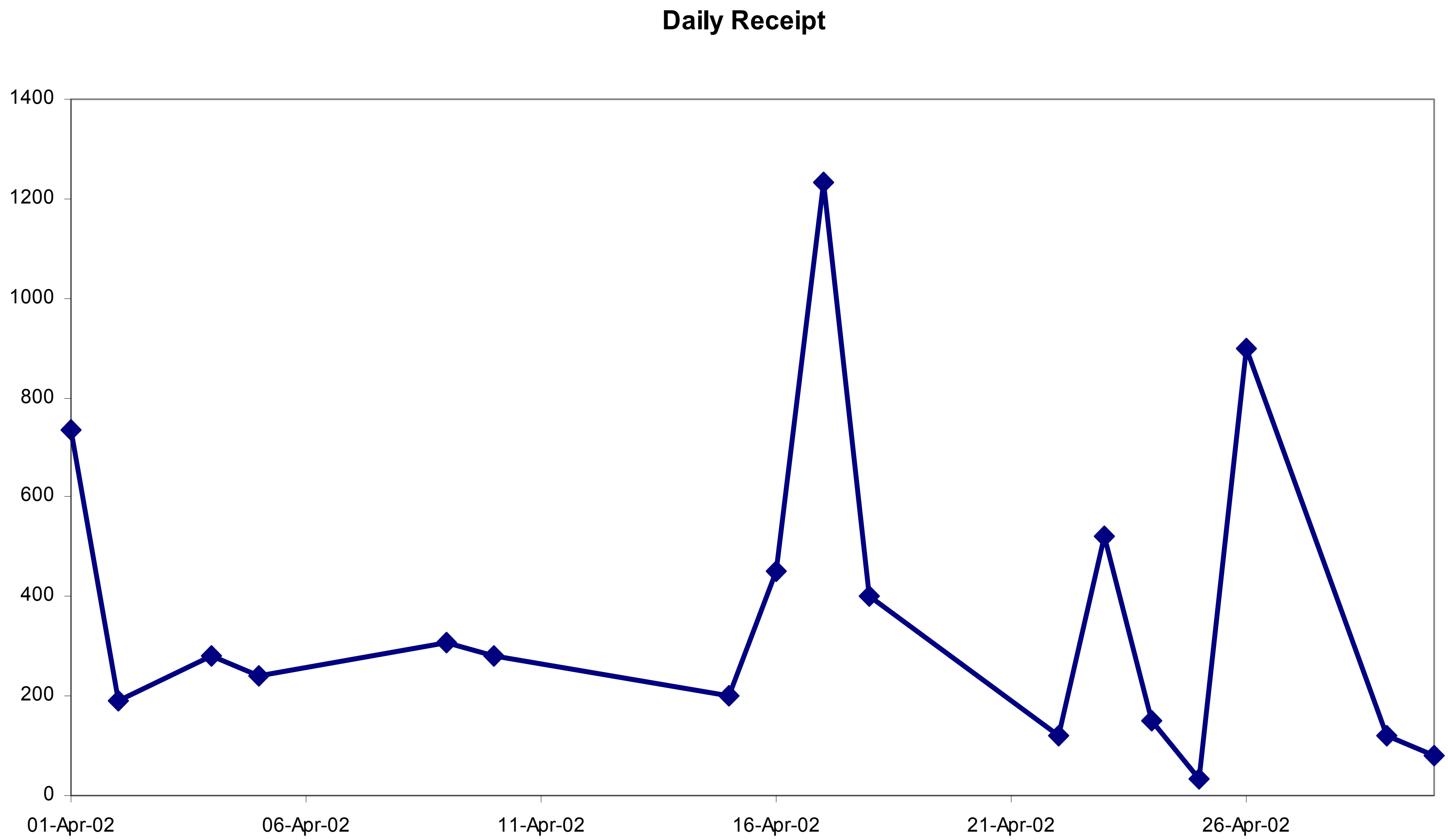
Capacity

- Changes in requirements create upstream inventory
- Changes in requirements raise transport costs

Reliability

- Distant suppliers subject to disruption

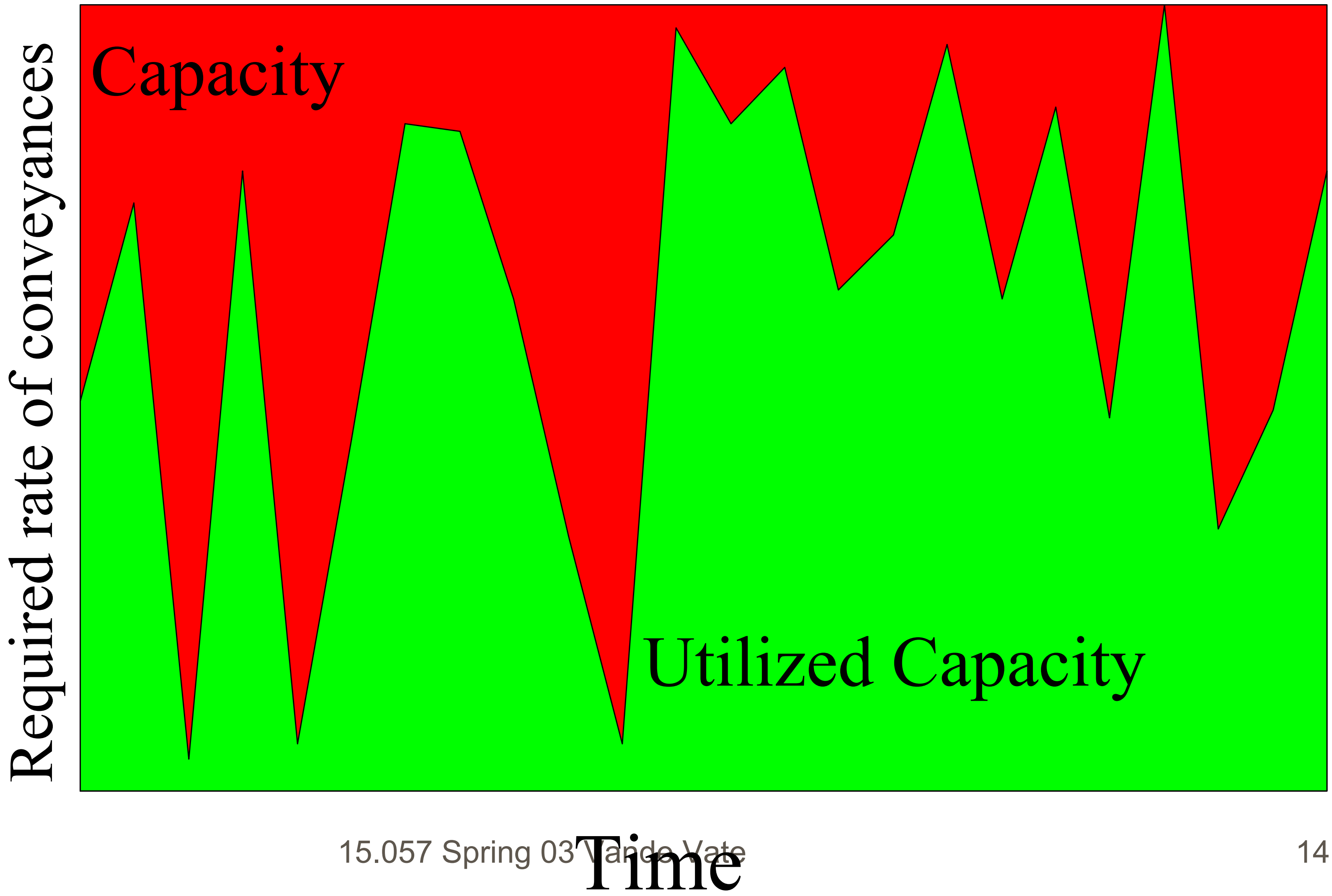
Release Variability



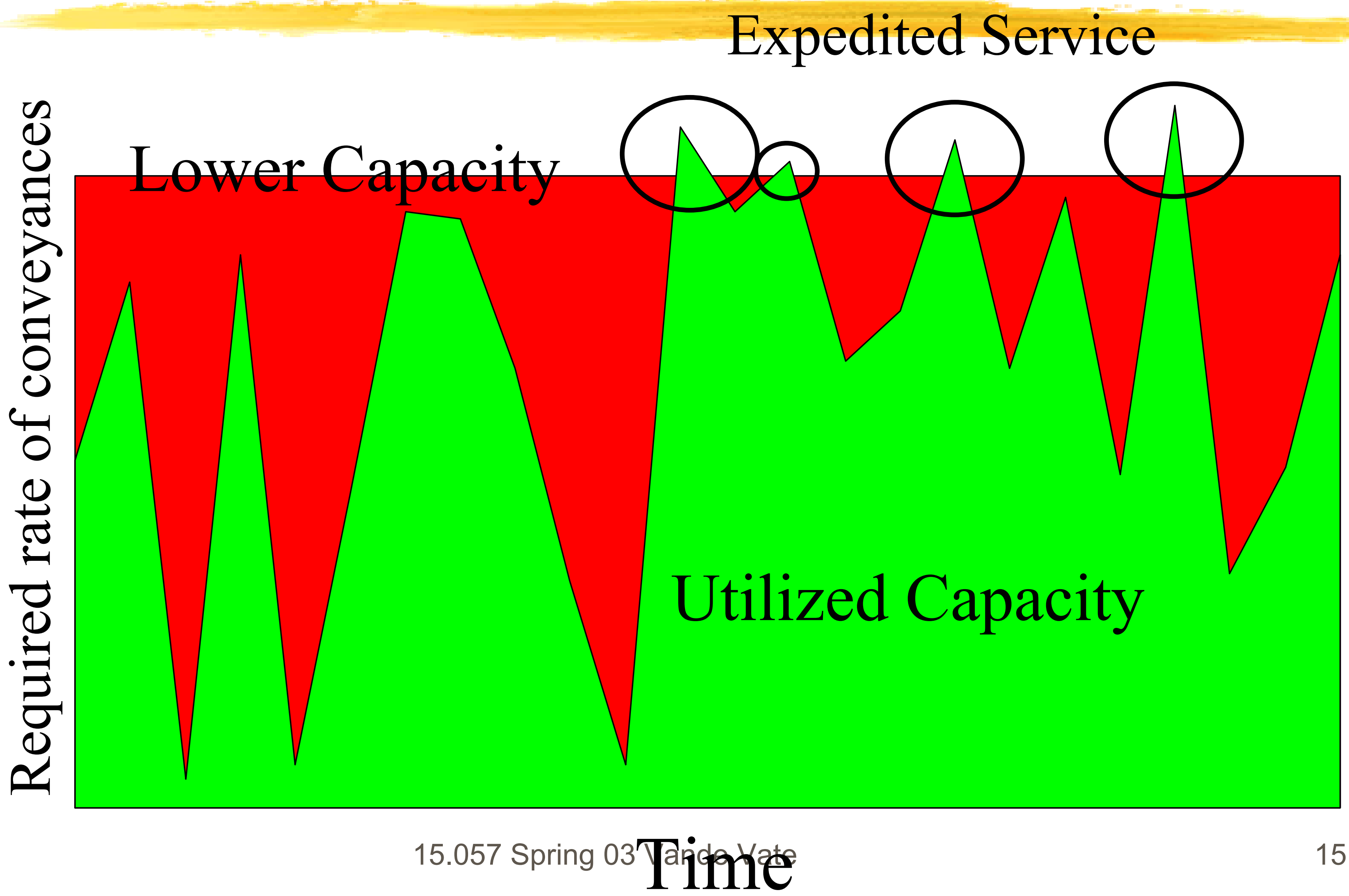
Managing Variability

- Capacity Buffer
- Inventory Buffer
- Time Buffer

Freight Cost



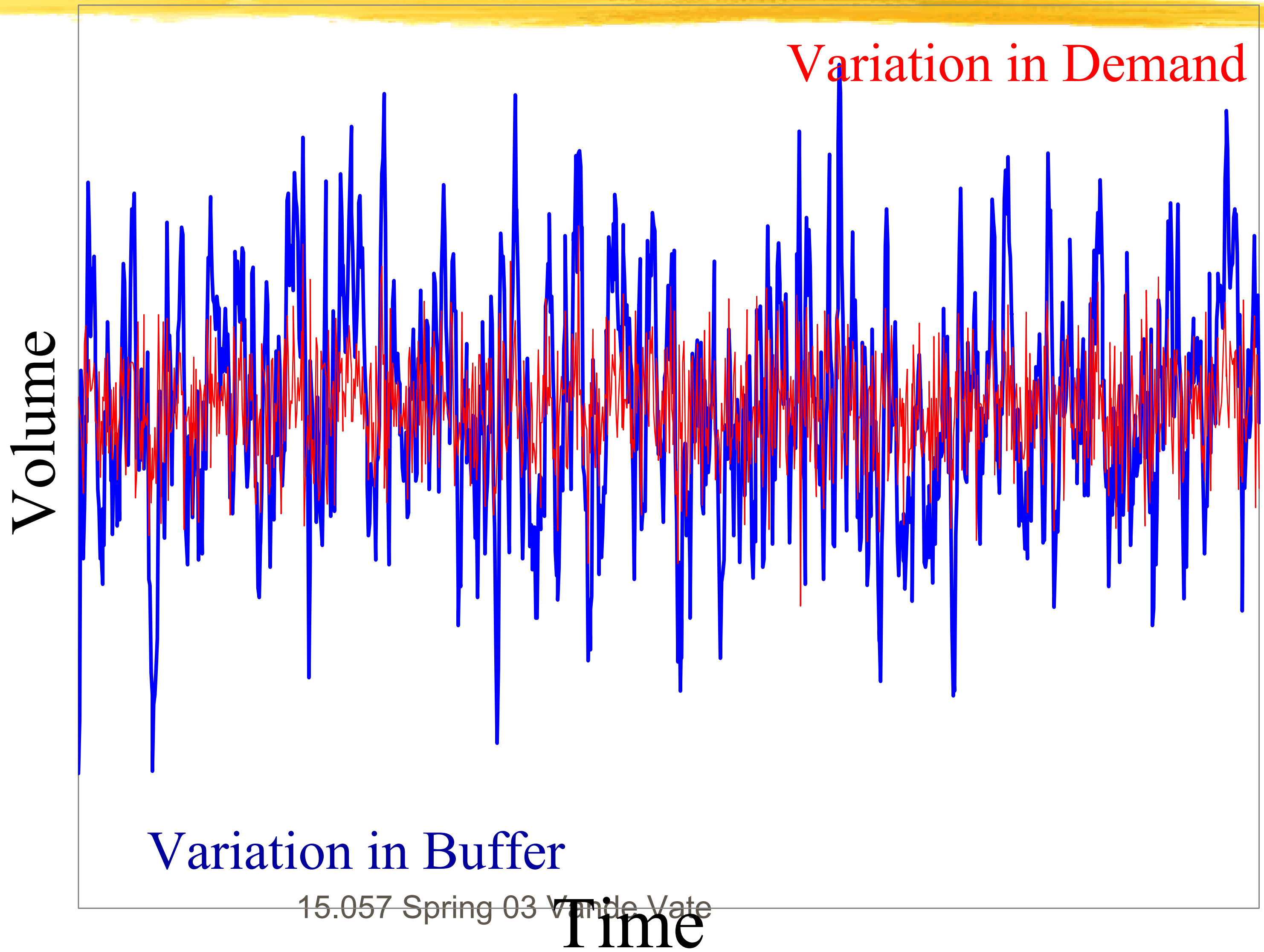
Expediting


Expedited Service
Lower Capacity
Utilized Capacity
Required rate of conveyances
Time

Ideal Supply Chain

- Same requirements every day
- No excess capacity
- No inventory
- No service failures
- Minimum Cost

Buffer Inventory with Constant Supply



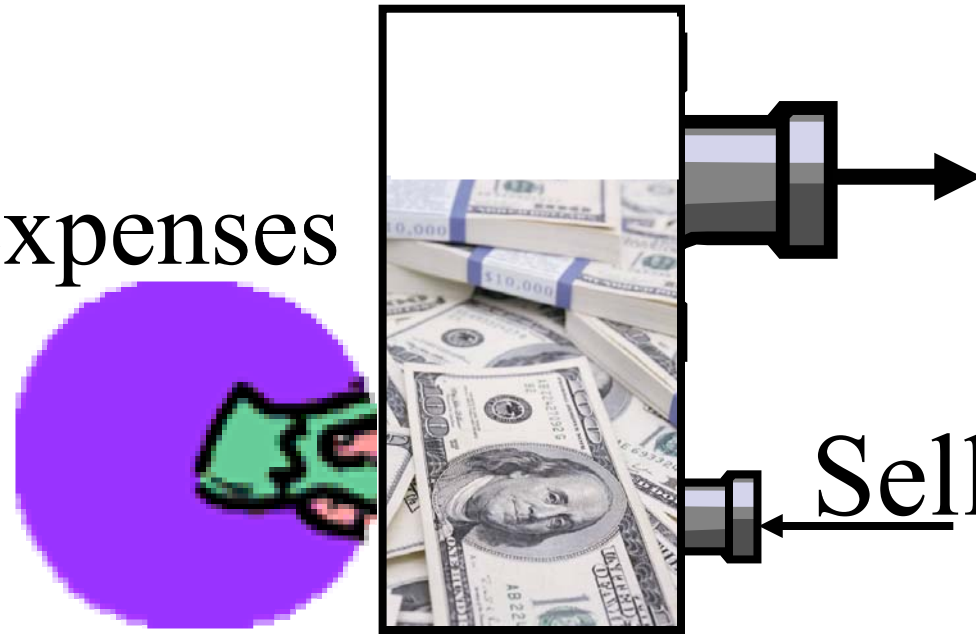
A Financial Model

From Revenues

Cash Expenses

Cash Acct

A Financial Model

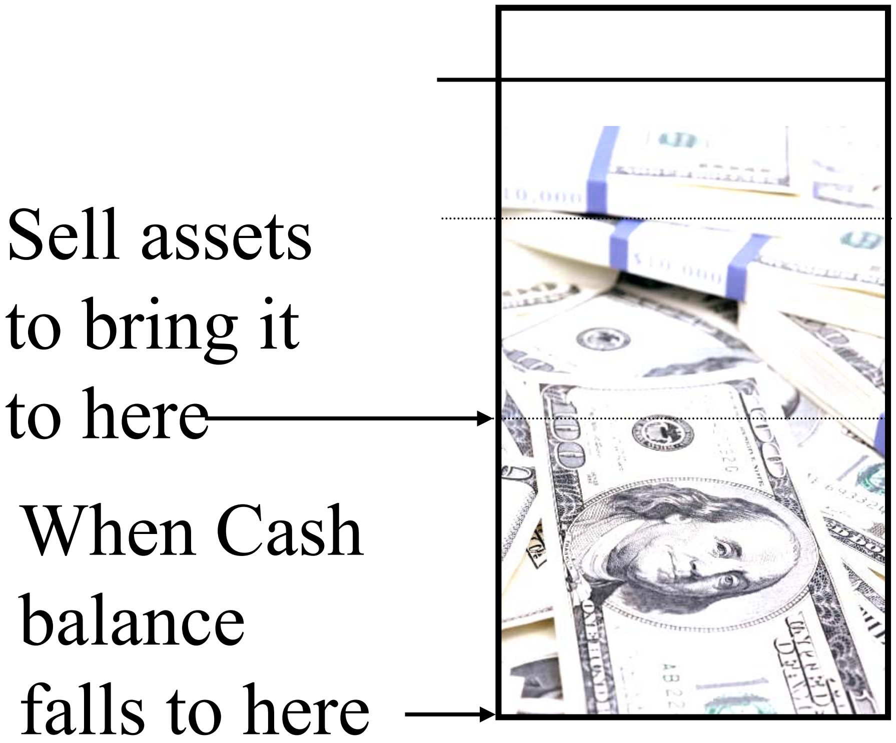


Controls

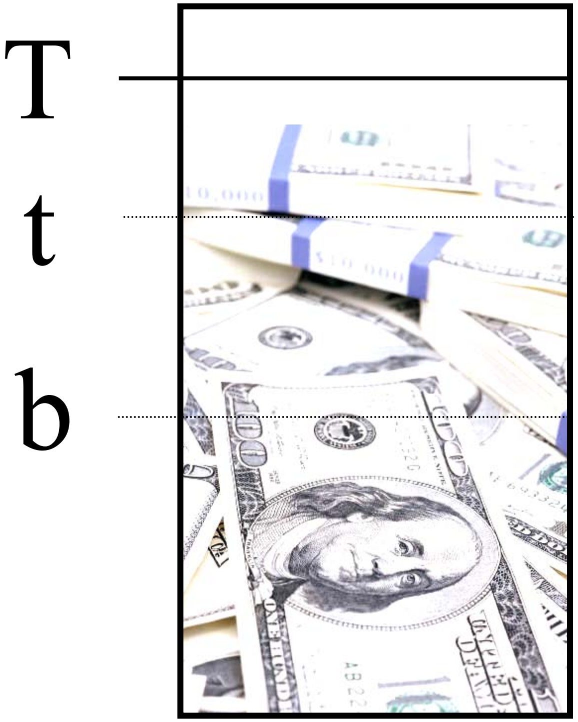
Invest enough to bring it to here

When Cash balance reaches here

Controls


Sell assets to bring it to here
When Cash balance falls to here

Controls



Trade-offs

- Opportunity cost of Cash Balance
- Transaction costs of investing and selling assets
- Set the controls, T, t and b to balance these costs

Inventory Analogy

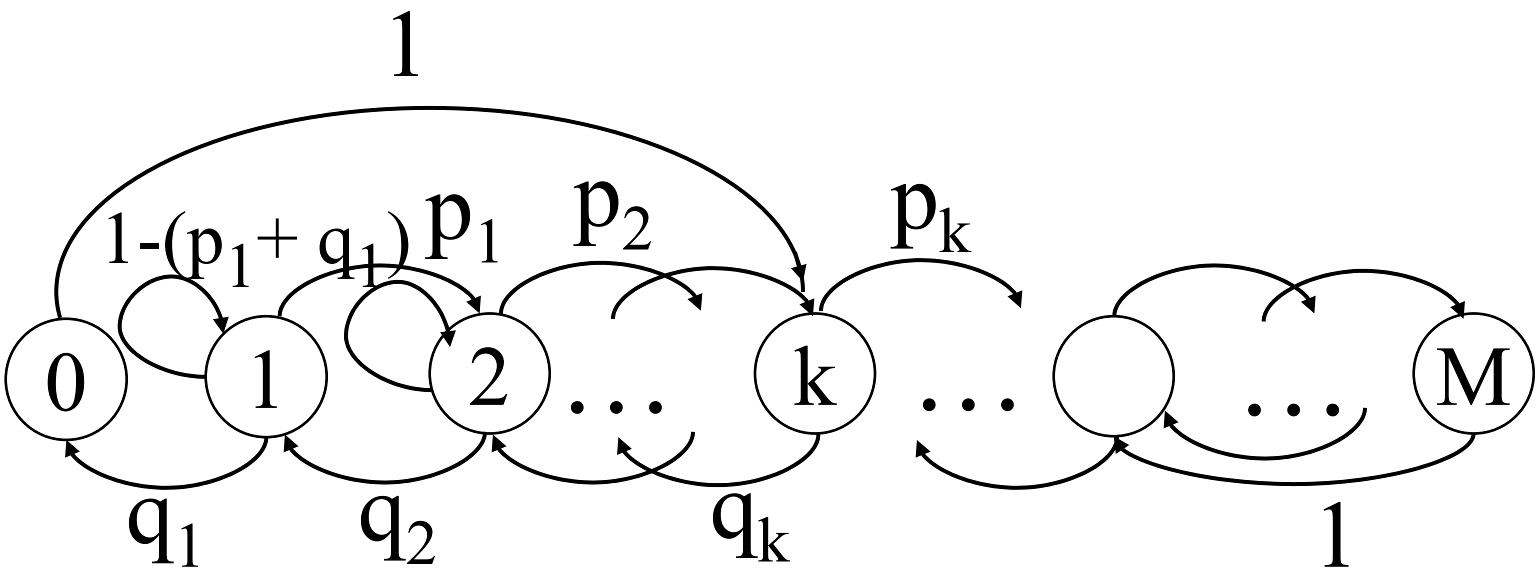
- Cash Expenses ⟷ Daily Production reqs.
- From Revenue ⟷ Constant supplies
- Sell Assets ⟷ Expedited order
- Invest Excess ⟷ Curtailed order

Trade-offs

- Opportunity cost of Cash Balance ↔ Cost of holding Inventory
- Transaction costs of investing and selling assets ↔ Supply chain costs of expediting and curtailing orders

- Set the controls, T, t and b to balance these costs

The Traditional Model

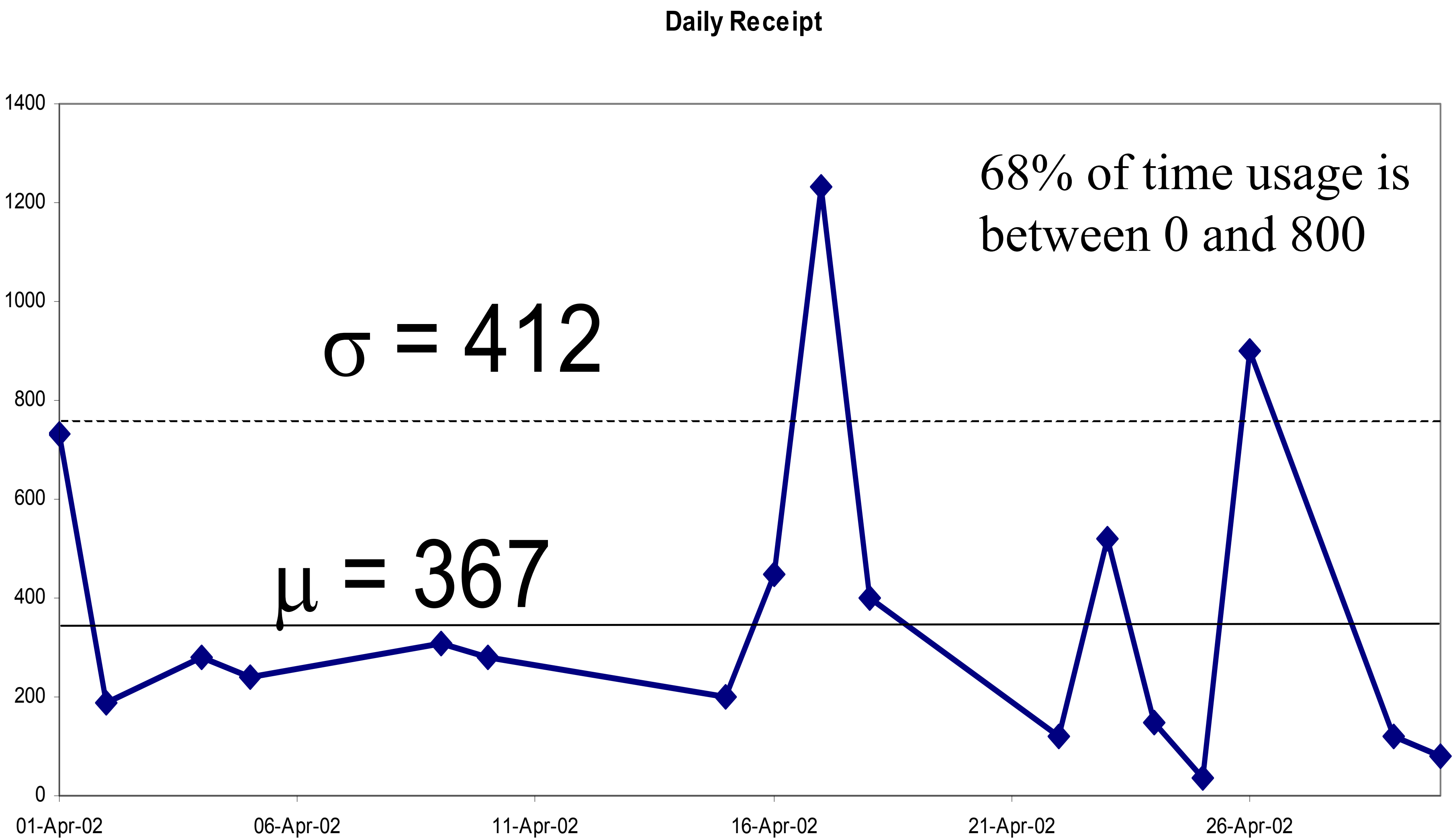


A Markov Model

Challenges

- Data intensive: p_i's and q_i's
- Computationally intensive
- Alternative
  - Brownian motion
    - Inventory behaves like
      - a random walk
      - Model of a particle in space
    - Two parameters: mean and variance
    - Advanced calculus methods make it "easy" to work with

Release Variability



The EOQ as a Special Case

- Average usage rate μ
- Variance in usage σ^2
- Nominal release rate $\lambda < \mu$
- Since we order less than we consume, inventory drifts downward
- How much should we "expedite" when it reaches 0?

Trade offs

- Expediting disrupts the supply chain
  - Fixed cost F for each time we expedite
  - Variable cost f for each item in the order
  - holding cost h for inventory
- Larger orders mean less frequent but larger disruptions and more inventory

EOQ as Special Case

- Order Q
- Time between orders is $Q/(\mu - \lambda)$
- Order frequency is $(\mu - \lambda)/Q$
- Average Inventory is $Q/2 + \sigma^2/2(\mu - \lambda)$
- Average Cost is
  - Expediting Cost: $(F+fQ)(\mu - \lambda)/Q$
  - Inventory Cost: $h(Q/2 + \sigma^2/2(\mu - \lambda))$

The Total Cost Formula

- $hQ/2 + F(\mu - \lambda)/Q + h\sigma^2/2(\mu - \lambda) + f(\mu - \lambda)$

EOQ: Transaction

Constant that doesn't depend on Q

EOQ: Inventory

- The best Q balances inventory and ordering costs:

$$hQ/2 = F(\mu - \lambda)/Q$$

$$Q^2 = 2F(\mu - \lambda)/h$$

$$Q = \sqrt{2F(\mu - \lambda)/h}$$

Fixed Expediting Quantity

- Find the best nominal release rate λ to get the right frequency of expediting

The Total Cost Formula

- $hQ/2 + h\sigma^2/2r + fr + Fr/Q$

EOQ: Transaction   EOQ: Inventory

Constant that doesn't depend on r

- The best drift rate $r = \mu - \lambda$ balances inventory and ordering costs:

$$h\sigma^2/2r = fr + Fr/Q$$

$$r^2 = h\sigma^2 Q/2(F+fQ)$$

$$r = \sqrt{h\sigma^2 Q/2(F+fQ)}$$

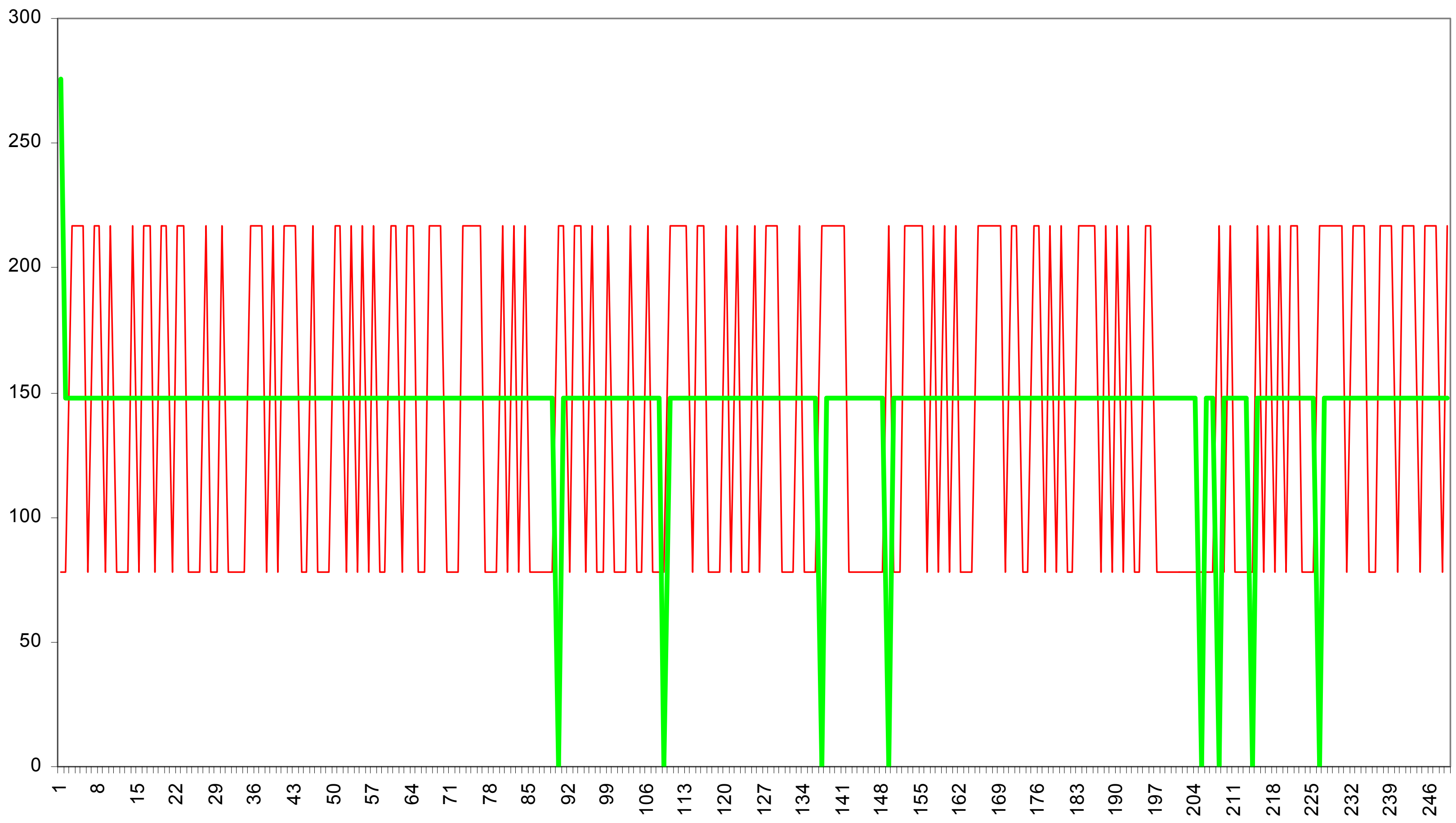
Two-sided Version

- If inventory grows too large, curtail shipments
- What's too large?
- How much should we curtail?
- If expediting is expensive
  - create a positive drift
  - order more than you need
  - curtail shipments when inventory is too high

Differences

- Constant Stream of Releases punctuated by Expediting and Curtailing
- If supplier can see inventory,
  - can anticipate expedited and curtailed orders
- Have to set a lower bound > 0 to protect against disruptions – safety stock

Example: Shipments



Example: Inventory