The Bullwhip Effect in Supply Chains

Leslie Gardner, Ph.D.
University of Indianapolis
School of Business
Institute for Emerging Careers
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- Funded by Lilly Endowment
- Research emerging and expanding career fields in Indiana as well as to find ways to prevent "brain drain."
- Identify future Indiana industries and determine careers needed to support future business development in Indiana.
$50,000 Grants

For emerging careers
- Develop curriculum
- Develop internships
- Do research to develop faculty expertise in area of emerging career
Supply-Chain Management

- Planning, organizing, directing, & controlling flows of materials
  - Begins with raw materials
  - Continues through internal operations
  - Continues through distribution of finished goods
  - Ends with returns or disposal of used up goods

- Involves everyone in supply-chain
  - Example: Your supplier’s supplier, logistics providers, information systems

- Objective: Maximize value & lower waste
  - Materials arrive when and where they should, JIT
  - Minimize excess inventory, minimize backorders
The Supply-Chain

Material Flow

Supplier → Manufacturing

Credit Flow

Manufacturer → Retailer

Schedules

Order Flow

Wholesaler

Cash Flow

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The Supply Chain

- **Supplier**
  - Inventory
- **Supplier**
- **Supplier**
  - Inventory
- **Manufacturer**
  - Inventory
- **Distributor**
  - Inventory
- **Customer**

Flows:
- **Market research data**
- **Scheduling information**
- **Engineering and design data**
- **Order flow and cash flow**
- **Ideas and design to satisfy end customer**
- **Material flow**
- **Credit flow**
Demand Amplification & Forrester Flywheel Effect

Reduce Inventories → Shortages

Excess Inventories

Increase in Safety Stock → Over Ordering

Late Deliveries
Bullwhip Effect

- With the Bullwhip effect demand order variability is amplified as one moves up the supply chain.
- This is because demand information is distorted as it is transmitted up the supply chain.
- Causes erratic shifts in orders up and down the supply chain.
  - Proctor and Gamble – Pampers
  - Hewlett-Packard - Printers
Symptoms of the Bullwhip Effect

- Excessive Inventory
- Poor Forecasts
- Insufficient and/or excessive capacities
- Unavailable Products
- Long Backlogs
- Costs for Expedited Shipments and Overtime
The Beer Game

- Developed at MIT more than 40 years ago to teach students about simulation and economic dynamics
- Does a good job of teaching students about the bullwhip effect but not how to prevent it
What can we learn from the Beer Game?

I have developed a Microsoft Excel simulation to test various strategies.

Goal – teach our students how to minimize the bullwhip effect.

Bullwhip effect does not occur unless backordering (filling orders late when product is available) is allowed.
Impact of Ordering Strategies on Bullwhip Effect

- Naïve forecast – order only what is ordered
- Exponential smoothing at $\alpha=0.1$, 0.5, and 0.9
- Order what is ordered plus cumulative backlog
- Order what is ordered + cumulative backlog unless inventory is some amount more than order + cumulative backlog
- Order what is ordered + this period backlog (not cumulative)
Naïve Forecast

- Order what was ordered from you
- Last time 4 units were ordered from you
  - Order 4 this time
- Last time 8 units were ordered from you
  - Order 8 this time
No bullwhip, but you never catch up on orders
Exponential smoothing at 0.1

\[ \text{Forecast} = (0.1)(\text{last actual}) + (1-0.1)(\text{last forecast}) \]

\[ \text{Forecast} = (0.1)(8) + (0.9)(4) = 4.4 \]

Order 4
No bullwhip, but retailer falls further and further behind.
Exponential smoothing at 0.5

Forecast = (0.5)(last actual) + (1-0.5)(last forecast)

Forecast = (0.5)(8) + (0.5)(4) = 6

Order 6
No bullwhip, but retailer, wholesaler and distributor are always behind
Exponential smoothing at 0.9

\[ \text{Forecast} = (0.9) \text{(last actual)} + (1-0.9) \text{(last forecast)} \]

\[ \text{Forecast} = (0.9)(8) + (0.1)(4) = 7.6 \]

Order 8
No bullwhip, but retailer, wholesaler and distributor are always behind, but not as far as for 0.5
Naïve plus cumulative backlog

Order what is ordered plus cumulative backlog
- Last time 12 were ordered from you, you have 8 in stock, and you have a backlog of 12
- Order 12+12=24
- Ship 8, your backlog is now 16

What happens upstream?
- The person upstream has nothing in stock, a backlog of 16, and 8 coming in
- He/she ships out the 8, now has a backlog of 32, and orders 24+32=56
Bullwhip with inventory staying high
Naïve plus backlog
no order if excess inventory

- Eventually, the material for the large orders starts flowing through the system and the placing of large orders ceases
- Inventory builds up and orders become small
- Quit ordering if orders are less than some amount of inventory
  - No order if order less than 3x inventory
    - Inventory = 144, last time 12 were ordered from you, don’t order any
  - No order if inventory is 12 more than order size
- Inventory gradually drains out
Compensate relative to order size - Bullwhip with inventory gradually draining out
Compensate with inventory anchor - Bullwhip
with inventory gradually draining out
Naïve plus one period backlog

Order what is ordered plus only this backlog, that is, the amount you were short this period

- Last time 12 were ordered from you, you have 8 in stock, and you have a backlog of 12
- Ship 8, your backlog is now 16, but you were only 4 short this time
- Order 12+4=16
Minimal bullwhip effect – inventories after bullwhip close but not quite on target
Lessons Learned

- Must compensate for backlog or you fall further and further behind
- Overcompensation for backlog causes bullwhip effect
- Undercompensation causes steady or increasing backlog
- Minimize bullwhip effect by right amount of compensation
Causes of Poor Compensation
Lee, Padmanabhan, Whang (1997)

1. Demand forecast updating
2. Order batching
3. Price fluctuation
4. Rationing and shortage gaming
Demand Forecast Updating

- Every manager will project demand based on what he/she sees. Managers at different levels project demand differently (signal processing).
- Safety stock complicates matters
Remedies for Demand Forecast Updating

- Make point-of-sale (POS) data available up supply chain
  - EDI
  - Internet
- Vendor managed inventory (VMI)
- Make downstream inventory and demand info available upstream
- Shorten lead-times
- Sell directly to consumer
Point of Sale Data (POS)

- Information on retailer order passed upstream
- Everyone orders what retailer ordered
No bullwhip effect but strange things happen to inventories
Order Batching

- Periodic ordering (once a month, once a week, etc.)
  - Cannot handle frequent order processing
  - Transportation costs – full-truckload cheaper than less-than-truckload rates

- Push ordering
  - Salespeople sign orders early to fill quotas when evaluated

- Periodic execution of MRP or DRP – sometimes order cycles overlap
Remedies for Order Batching

- Reduce ordering cost
  - EDI
  - Blanket orders
  - VMI
- Mixed SKU truckloads
- 3PLs
Price Fluctuation

- Special promotions, discounts, etc. cause forward buying, that is, consumers buy in larger quantities and don’t buy again until their stocks are depleted.
- Surges in shipments causes premium shipping costs.
- Larger inventories to handle surges result in damage, deterioration, obsolescence.
Remedies for Price Fluctuation

- Stabilize prices
  - Reduce wholesale price discounting
  - Uniform pricing policies
- Activity-Based Costing
  - Conventional accounting practices may not show hidden costs of inventory, storage, special handling, premium transportation, etc.
Rationing and Shortage Gaming

- When demand exceeds supply, manufacturers ration products on the basis of amounts ordered.
- Customers exaggerate needs to get more.
- When demand cools, customers cancel orders, manufacturers stuck with excess.
Remedies for Rationing and Shortage Gaming

- Allocate in proportion to past sales records
- Plan ahead, share information
- Penalize returns
Summary

Supply chain management is a cutting edge business strategy that integrates internal and external logistics across many manufacturers, suppliers, distributors, retailers, transportation providers, and third party logistics firms to increase productivity and to obtain a competitive advantage for all parties involved.