Taming the Bull

Mitigation of Inventory and Ordering Amplification in Multi-Echelon Supply Chains

James E. Paine

MIT Sloan School of Management – System Dynamics Group

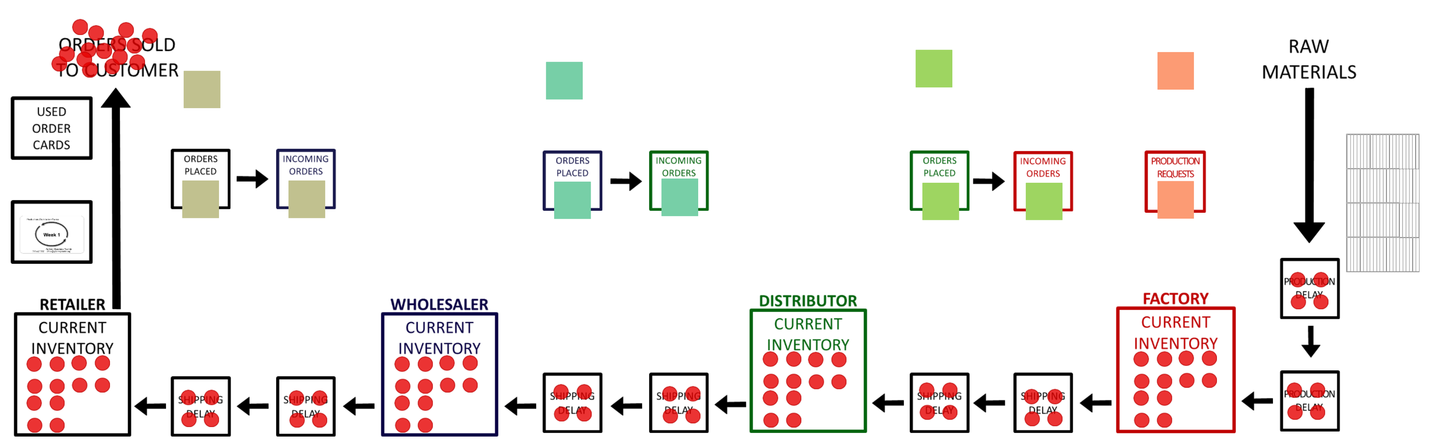
MIT MANAGEMENT SLOAN SCHOOL

BACKGROUND

- **Bullwhip Effect** is the increasing amplitudes in both orders and on-hand inventory positions the further one moves away from a source of order variability
- This is a ***persistently observable*** phenomena in supply chains
- **Project Goal:** develop an algorithm capable of mitigating bullwhip that is:
  - ***Useful***
  - ***Implementable***
  - ***Understandable***

MODELING FRAMEWORK: THE BEER GAME

- **The Beer Game** is a classical inventory management and System Dynamics simulation and learning tool
- Multi-agent decentralized supply chain is modeled, much like real decentralized inventory management systems
- ***Nearly 50 years of history*** (and data) at MIT as use as a business simulator and teaching tool



MODELING METHODOLOGY

- Simulatable and functional form of the Beer Game created
  - Self-contained simulation of the system over a given time horizon
  - Callable function that takes a given state-action pair and returns an updated state
- Created dynamic environment to train a model based on *actual* performance and feedback in the Beer Game

Visit

github.mit.edu/jpaine/Taming-the-Bull

...for documented simulation code, full report write-up, citations, and to keep up with project progress!

MODELING HUMAN BEHAVIOR

- **Human Behavior Modeled from historic data**

$$O_t = MAX\left(0, \widehat{L_t} + \alpha_S\left(S' - S_t - \beta\, SL_t\right) + \varepsilon_t\right)$$

$$where\ \widehat{L_t} = \theta L_{t-1} + (1-\theta)\hat{L}_{t-1}$$

- Parameters roughly translate as
  - Θ ≈ smoothing of the expected inventory loss next round
  - α ≈ influence of net on hand stock less inbound supply line
  - β ≈ influence of inbound supply line
  - S' ≈ Next inventory position

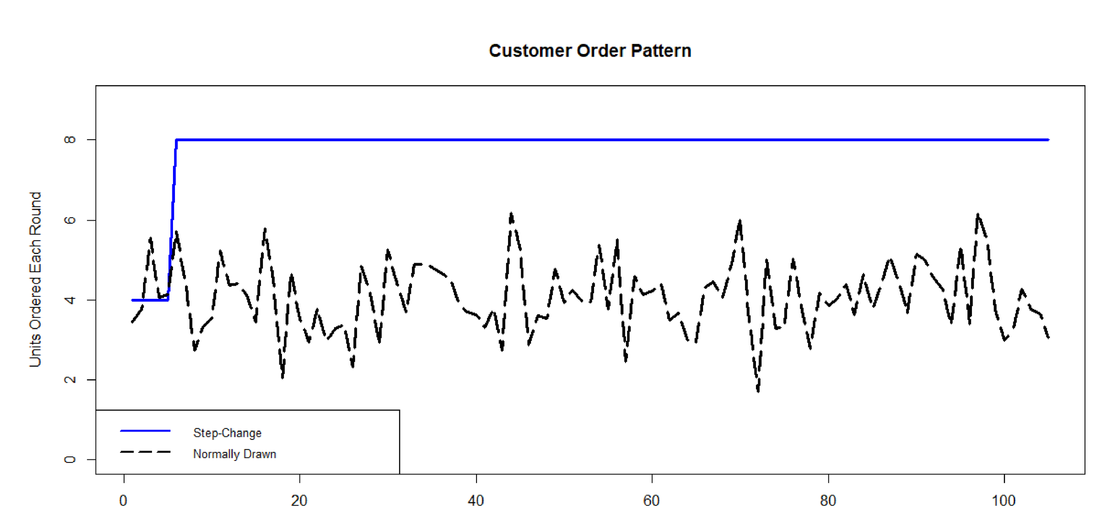
OPTIMIZING THE AGENT

- **Directly optimized** the four parameters in the fitted human model
- Optimized across each of the four positions, with remaining three using average parameters fitted to historic Beer Game runs
- Explored optimization using three different methods
- Optimized across **two different cost functions**

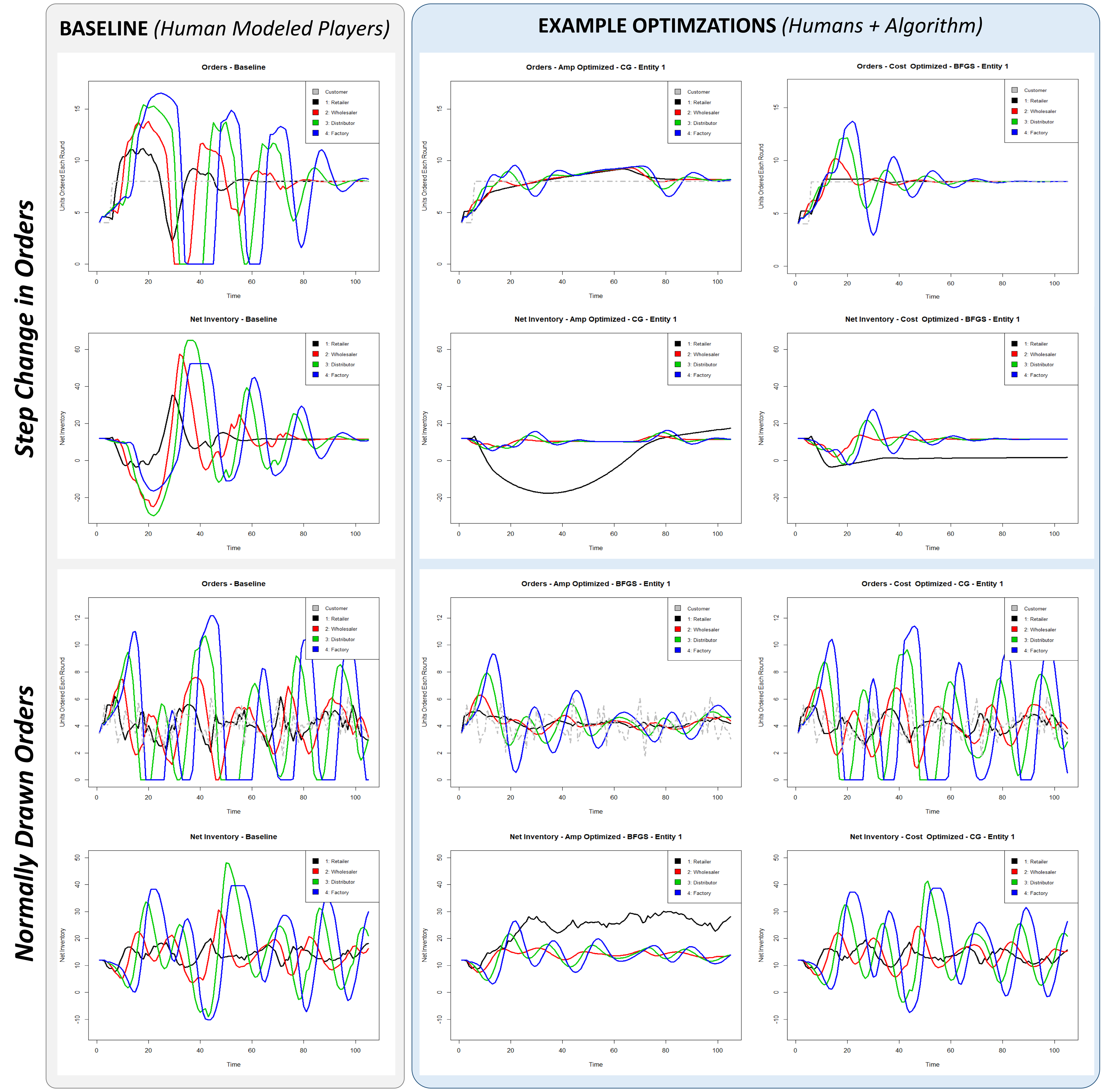
$$Cost_{inventory-based} = \sum_{t=1}^{T} \sum_{entity=1}^{N} \left(C_{bo} * Backorders_{t,n} + C_{inv} * Inventory_{t,n}\right)$$

$$Cost_{amplification-based} = \sum_{t=1}^{T} \left\{ \sum_{entities=1}^{N} \left[\gamma \left(\frac{Orders_{t,n} - CustomerOrders_t}{CustomerOrders_t} \right)^2 + \psi \right] \right\}$$

- Optimized against step-increase in customer demand
- Tested against ***both*** *step-change* and *normally drawn demands*



SELECTED RESULTS



CONCLUSIONS

- ***It is possible*** **to construct an optimized agent that** ***mitigates bullwhip***
- Use of existing human-based decision modeling allows for optimization to be ***understandable***
  - Optimized agents at the extrema of the supply chain act as base-stock level seeking agents (low θ and β)
  - Optimized agents in the middle of the supply chain act as risk-adverse inventory buffers (high S' and β)
- **Next steps:** empirical study of bullwhip mitigation using optimized agent with real players and development of Policy Gradient-based agent